NASA
CR
3624
c.1

TECH LIBRARY KAFB, NM
0062151
LOAN COPY: RETURN TO AFWL
TECHNICAL LIBRARY, KIRTLAND AFB, N.M.

NASA Contractor Report 3624

# WISGSK

## A Computer Code for the Prediction of a Multistage Axial Compressor Performance With Water Ingestion

T. Tsuchiya and S. N. B. Murthy

GRANT NAG-3-62
NOVEMBER 1982

NASA

TECH LIBRARY KAFB, NM

0062151

NASA Contractor Report 3624

# WISGSK

## A Computer Code for the Prediction of a Multistage Axial Compressor Performance With Water Ingestion

T. Tsuchiya and S. N. B. Murthy
*Purdue University*
*West Lafayette, Indiana*

Prepared for
Lewis Research Center
under Grant NAG-3-62

National Aeronautics
and Space Administration

**Scientific and Technical**
**Information Branch**

1982

## TABLE OF CONTENTS

LIST OF SYMBOLS

| | |
|---|---|
| $C_p$ | Specific heat at constant pressure |
| $D_o$ | Initial droplet diameter |
| $D_{eq}$ | Equivalent pressure ratio |
| $i$ | Incidence angle |
| $K$ | Deviation constant |
| $N$ | Rotor speed |
| $N/\sqrt{\theta}$ | Rotor corrected speed |
| PR | Stagnation pressure ratio |
| $P_{01}$ | Stagnation pressure at stage inlet |
| $P_{02}$ | Stagnation pressure at stage outlet |
| $P_{02}/P_{01}$ | Stagnation pressure ratio |
| $P_{ref}$ | Reference pressure |
| TR | Stagnation temperature ratio |
| $T_{01}$ | Stagnation temperature at stage inlet |
| $T_{02}$ | Stagnation temperature at stage outlet |
| $T_{02}/T_{01}$ | Stagnation temperature ratio |
| Tref | Reference temperature |
| $U$ | Blade speed |
| $U_{tip}$ | Blade speed at tip |
| $V_z$ | Axial velocity |
| $V_{z1}$ | Axial velocity at stage inlet |
| $V_{z2}$ | Axial velocity at stage outlet |
| $W_1$ | Blade relative velocity at stage inlet |
| $W_2$ | Blade relative velocity at stage outlet |

| | |
|---|---|
| $X_w$ | Water content (mass fraction) |
| $X_{w,o}$ | Initial water content |
| $\beta_1$ | Relative flow angle at rotor inlet |
| $\beta_2$ | Relative flow angle at rotor outlet |
| $\gamma$ | Ratio of specific heats |
| $\zeta$ | Adiabatic efficiency |
| $\Delta T_0$ | Rise in stagnation temperature across a stage |
| $\delta$ | Deviation angle |
| $\delta$ | Corrected pressure ($\delta = P/P_{ref}$) |
| $\varepsilon$ | Deflection angle ($\varepsilon = \beta_1 - \beta_2$) |
| $\Theta$ | Corrected temperature ($\theta = T/T_{ref}$) |
| $\sigma$ | Solidity |
| $\phi$ | Flow coefficient |
| $\psi$ | Pressure-rise coefficient |

Subscript

| | |
|---|---|
| 0 | Stagnation value |
| 1 | Stage inlet |
| 2 | Stage outlet |
| tip | Blade tip |
| z | Axial direction |

Superscript

| | |
|---|---|
| * | Pertaining to design point |

## SUMMARY

A computer code for predicting the performance of an axial-flow compressor with water ingestion has been developed at Purdue University under the NASA Grant NAG 3-62 and presented along with a test case that illustrates the use of the Code. The Code employs the same procedure and architecture as the NASA-STGSTK Code. The Code uses a meanline stage stacking method; stage and cumulative compressor performance is calculated utilizing representative triangles located at rotor inlet and outlet mean radii.

The aero-thermo-mechanical interactions arising during air-water droplet mixture flow are taken into account in terms of four processes: (i) changes in blade performance parameters (deviation and efficiency), (ii) centrifugal action due to flow rotation, (iii) heat and mass transfer processes between the gaseous and liquid phases and (iv) droplet instability and break-up. The latter three are introduced at the exit of each blade row. The aerodynamic performance of a stage is based on estimated rules for deviation and efficiency with air-water mixture flow. The nature of such rules is discussed in detail.

The Code provides options for the calculation of performance with (a) mixtures of gases such as air and water vapor and (b) air-water droplet mixtures with different water content.

The Code is useful in obtaining preliminary estimates of overall performance of compressors with water ingestion given the design point details corresponding to air flow and the nature of corrections for air-water mixture flow.

# CHAPTER I

## INTRODUCTION

Water ingestion into jet engines may arise due to various circumstantial reasons: high humidity in air resulting in condensation of water at the inlet, tire-generated spray entering the air stream during take-off and landing on rough runways with puddles of water, and flight through rain storms. It has been found that such water ingestion can lead to a loss of performance, engine mismatch, and loss of surge margin, and in some cases causes undesirable mechanical and aerolastic effects. Both steady state and transient performance are affected and the operational margins in the control system also become affected. With ingestion of large amounts of water, water may flow through the engine at low power settings and a flameout may arise at higher power settings. From the point of view of criticality of changes in the performance of different engine components, the compressor presents unique problems and is in many ways central to the performance of the engine (References 1 and 2).

The air-water mixture ingested into a compressor is characterized by the water content, the droplet size distribution and the vapor content. The mixture may enter the compressor nonuniformly in the circumferential and radial directions. In the case of rain water ingestion, the water content may range from 2.0 percent to 15.0 percent or more. The water droplet size variations in rain and mist are presented in Figure 1. Water vapor content in the atmosphere varies with the degree of saturation and the altitude. Figure 2 presents the variation of water vapor content corresponding to the saturation state as a function of altitude. Some typical values of vapor content corresponding to the

saturation state under different temperature and pressure conditions that are of interest in aircraft operation are given in Table 1.

At the end of each stage, and therefore also at the exit of a multistage compressor, the characteristics of the air-water mixture undergo modification: water, vapor and air become redistributed; the work done on the gaseous phase and efficiency become affected; and the stalling characteristics of stages undergo changes.

The performance of a compressor stage at a given speed and flow coefficient undergoes a change during water ingestion, compared to the performance with air flow, on account of a combination of processes associated with droplet-laden air flow:

(i) change in airfoil performance;
(ii) centrifugal action causing motion and accumulation of water and vapor towards the tip and hub sections, respectively; and
(iii) heat and mass transfer between the two phases.

These processes become further complicated due to:

(a) droplet impact and rebound at the blades and casing,
(b) droplet reingestion from blade surfaces into wakes,
(c) droplet break-up to remain under the critical size and
(d) droplet size distribution.

For a given compressor with specified

(i) blade and blade-loading,
(ii) aspect ratio and
(iii) interstage spacing

one can examine the changes in performance in terms of two major parameters:

(a) changes in aerodynamic performance and
(b) characteristic times available for centrifugal action and heat and mass transfer processes.

The changes in a given compressor depend upon the following:

(i) operating speed and throttle setting;
(ii) water and water vapor mass fractions in the air-water mixture

TABLE 1

SATURATION VALUES OF WATER VAPOR
UNDER TYPICAL CONDITIONS

| | TEMPERATURE ($^{o}$F) | PRESSURE (psi) | WATER VAPOR $w_s$ $\left[\frac{lb_m, \text{ vapor}}{lb_m, \text{ dry air}}\right]$ | $w_s^*$ $\left[\frac{lb_m, \text{ vapor}}{lb_m, \text{ mixture}}\right]$ |
|---|---|---|---|---|
| | 59 | 14.696 | 0.011 | 0.011 |
| | 86 | 14.696 | 0.027 | 0.026 |
| | 104 | 14.696 | 0.049 | 0.047 |
| A | 125.4$^{(1)}$ | 22.402$^{(4)}$ | 0.060 | 0.057 |
| | 155.8$^{(2)}$ | 22.402$^{(4)}$ | 0.148 | 0.129 |
| | 176.1$^{(3)}$ | 22.402$^{(4)}$ | 0.275 | 0.216 |
| | 65.1$^{(5)}$ | 12.648$^{(6)}$ | 0.025 | 0.024 |
| | 212 | 15.698 | 9.124 | 0.901 |
| B | 212 | 15.494 | 11.459 | 0.920 |
| | 212 | 15.365 | 13.661 | 0.932 |

Note: Condition corresponding to

(1) Mach number = 0.8 when T = 59$^{o}$F
(2) Mach number = 0.8 when T = 86$^{o}$F
(3) Mach number = 0.8 when T = 104$^{o}$F
(4) Mach number = 0.8 when p = 14.696 psi
(5) Mach number = 0.8 when T = 5.55$^{o}$F
(6) Mach number = 0.8 when p = 8.298 psi

$\left.\begin{matrix}(5)\\(6)\end{matrix}\right\}$ 15,000 ft. altitude

flow at entry; and

(iii) water droplet size distribution.

In order to determine the performance of an axial flow compressor based on the aforementioned physical model, a three-dimensional flow calculation procedure is eventually desirable. However there are at present considerable uncertainties in regard to the various two phase flow processes associated with droplet-laden gas flow in general and in axial-flow compressors in particular. It is therefore considered that a parametric mean-line (one-dimensional) model should be developed in the first instance for determining the overall performance of a compressor stage with water ingestion. Such a calculation scheme requires incorporation of a stage-stacking procedure for use in multi-stage machines.

The current report describes such a calculation procedure written in the form of a computer code named the NASA-WISGSK Code. It is similar to the NASA-STGSTK Code (Reference 3) written for the purposes of calculating the off-design performance of axial-flow compressors given the details of the design point.

## 1.1 Background

A model for the calculation of overall performance of a multi-stage axial-flow compressor was developed based upon a mean-line, stage-stacking procedure (Reference 4). The model incorporates all of the essential features of droplet-laden air flow:

(i) droplet motion during ingestion,

(ii) droplet-blade interactions,

(iii) blade performance changes,

(iv) centrifugal action,

(v) heat and mass transfer processes and

(vi) droplet break-up.

Two limiting cases have been considered:

(i) droplets generally following the air flow path and

(ii) droplets having equal probability of motion in all directions. Figure 3 illustrates the latter case which applies to large droplet sizes. The calculation procedure adopted with the model is

(a) to calculate a blade row (rotor or stator) performance for two phase flow and

(b) to "correct" the exit conditions for centrifugal action and heat and mass transfer based upon the (characteristic) times available for those processes, and for droplet size changes based on the concept of a critical diameter.

In order to calculate the transport and accumulation of water radially outwards, the flow is divided into ten streamtubes along the span and the calculations are carried out in the time domain over the available time (across the blade row). Water on the surface of blades is distinguished from that in the blade passages. The corrected conditions constitute the inlet conditions for the next blade row, and so on for various stages in a multistage machine. The calculation procedure, the associated computer code, namely the PURDU-WICSTK Code, and an illustrative case are presented in Reference 5.

The foregoing calculation procedure permits determination of the aerodynamic performance of a chosen section (such as the mean section), a compressor stage at given initial and operating conditions provided the details of the blade section are available. In other words, at design and at off-design conditions, the deviation of fluid flow over a blade section and the efficiency of the blade section are determined directly for given initial flow conditions.

The calculation procedure also permits such a direct determination of blade performance at other spanwise locations of a stage provided that, once again, details regarding the section under consideration are available. Such a calculation is again performed on a one-dimensional basis. It is, of course, necessary to account for the redistribution of water and water vapor due to centrifugal action across the span of the compressor. Thus, in most cases the hub sections may become depleted of water but repleted with water vapor, and there may arise

an appreciable accumulation of water in the tip sections. In the case of a compressor with many stages, there may also arise a change in the condition of the fluid mixture at the mean section of a stage.

The calculation procedure can be utilized for any specified inlet mixture of air, water and water vapor. When calculations have been performed for a compressor stage under a variety of conditions, one of the interesting results that can be obtained is a set of correlation rules for

(a) diffusion factor and

(b) efficiency for the particular type of blading in terms of flow coefficient and mass fraction of water content.

Such correlation rules may then be used to obtain off-design performance of the compressor utilizing a considerably simplified procedure such as for example the procedure of the NASA-STGSTK Code.

It will be recalled that the blade outlet conditions obtained on the basis of droplet-laden air flow over a blade section need to be "corrected" for (a) centrifugal action, (b) heat and mass transfer processes between the gaseous and the liquid phases and (c) droplet size adjustment according to the PURDU-WICSTK Code procedure. The corrected values then represent the final outlet conditions from a stage and thus the initial conditions into a following stage, if any.

The correlation rules for diffusion factor and efficiency are therefore of use only to obtain the initial aerodynamic performance of a blade section with two phase flow. The correlation rules will apply to the compressor for which they have been obtained utilizing the PURDU-WICSTK Code.

By performing such calculations on a number of compressors with different types of blading it is expected that distinct trends can be established in the correlation rules. It is then possible to utilize the generalized correlation rules for specific types of blading and thus to calculate the off-design performance of compressors.

The NASA-WISGSK Code, described in this Report, has been designed assuming that such correlation rules are available.

## 1.2 Illustrative Example

The utilization of the NASA-WISGSK Code is illustrated here utilizing the design details for a small 6-stage axial-flow Test Compressor consisting of the axial stages of a T-63 engine. Details regarding the Test Compressor are provided in Appendix 1.

It is of interest to point out that a series of tests has also been conducted on the Test Compressor with water ingestion, and the results of such tests have been reported in References 6 and 7.

## 1.3 Outline of the Report

Chapter II of the Report is devoted to a description of the overall program. The subroutines and external functions are listed in Chapter III. A listing of the input data and the output obtained in the code are given in Chapters IV and V respectively. In Chapter VI, an illustrative test case is presented along with a discussion on the utilization of the code.

# CHAPTER II

# OVERALL PROGRAM DESCRIPTION

The NASA-WISGSK Code is based on two earlier studies:

i) the development of the PURDU-WICSTK Code for the calculation of the performance of multi-stage compressors with water ingestion (Reference 5); and

ii) the NASA-STGSTK Code for the determination of the off-design performance of axial-flow compressors (Reference 3).

## 2.1 Description of the PURDU-WICSTK Code and the NASA-STGSTK Code

### 2.1.1 The PURDU-WICSTK Code

The one-dimensional flow equations for two phase flow in axial compressors have been derived in detail and presented in Reference 4. Those equations are suitable for the calculation of performance of any chosen section along the span of an axial compressor blade row. The PURDU-WICSTK Code is based on those equations. For given initial conditions at the entry to a stage, the outlet conditions can be calculated using those equations.

The PURDU-WICSTK program deals with a fluid that may consist of (a) a mixture of three different gases and (b) a mixture of two types of water droplets, distinguished by size. The mixture of gases may consist of air and water vapor along with another gas when necessary. The water droplets may be either "small" or "large" diameter droplets or a mixture of small and large droplets. Small droplets are defined as those that follow the gas flow path and hence, absorb work input into the compressor along with the gaseous phase. Large droplets are assumed to move largely independently of the gas phase, with equal probability of motion in all directions, and without absorbing work

input but introducing drag losses. Currently one can only choose the sizes for small and large droplets in an arbitrary fashion; for example if small droplets are assumed to be of mean diameter equal to 0(10 μm) large droplets may be assigned a mean size of about 1,000 μm in diameter. In a general two-phase mixture that is utilized as the working fluid in a compressor, the proportion of various constituents (namely, differnt gases and two types of droplets) may be chosen as desired in the initial conditions assumed for a calculation. Thus, to consider humid air carrying large droplets, the content of small droplets is set equal to zero while water vapor content is related to humidity.

The performance of a stage of a compressor is based in the PURDU-WICSTK Code on five physical models as follows:

(1) Model for the calculation of stage performance with respect to the gaseous phase and water droplets.
(2) Model for droplet motion across a blade row from a chosen upstream location to a designated downstream location.
(3) Model for centrifuging of water droplets.
(4) Model for heat and mass transfer processes between the two phases; and
(5) Model for droplet break-up and equilibration with respect to size.

The foregoing five models have been described in detail in Reference 5. The performance of a stage is calculated for given initial and operating conditions with respect to the gaseous phase and the water droplets. Regarding small droplets, any fraction of their total number may be taken into account depending upon assumptions relating to droplet impingement and rebound processes. Then, at the exit of a blade row, the three major processes, namely (1) centrifugal action on droplets, (2) heat and mass transfer processes between the two phases and (3) droplet size adjustment, are taken into account. When the stage performance parameters are "corrected" for the afore-mentioned three processes, one obtains the final outlet conditions from a stage. The

outlet conditions from a stage are modified, to account for geometry of compressor, in order to obtain the initial conditions for the next stage, where such exists. Calculations are repeated for subsequent stages based on the well-known concept of stage-stacking. The Code can be used to predict the design point performance as well as off-design performance of a multi-stage compressor.

### 2.1.2 The NASA-STGSTK Code

The details regarding the NASA-STGSTK Code are given in Reference 3.

## 2.2 Correlations of Performance Parameters with Water Ingestion

The two principal performance parameters for axial-flow compressor blading are (i) the stage pressure-rise coefficient and (ii) the aerodynamic efficiency of a blade row. These may be expressed as functions of flow coefficient for air flow and air-water mixture flow through the compressor. The stage pressure-rise coefficient can be obtained from a knowledge of deflection of the working fluid over a rotor blade row or from a knowledge of blade metal angles and incidence and corresponding deviation angles.

The methods of obtaining correlations for (i) deviation of the working fluid over a blade, (ii) the stage pressure-rise coefficient and (iii) the aerodynamic efficiency of blade rows are described in the following.

### 2.2.1 Deviation Angle

A general rule for deviation may be written as follows (Reference 9).

$$\delta-\delta^* = k\ (D_{eq} - D_{eq}^*) \tag{2.1}$$

where $\delta$ and $D_{eq}$ are the deviation angle and the equivalent diffusion ratio, respectively; $(\ )^*$ denotes values at the reference point; and k is a (porportionality) constant. According to Lieblein (Reference 8), the equivalent diffusion ratio can be written as follows:

$$D_{eq} = \frac{\cos\beta_2}{\cos\beta_1} \cdot \frac{V_{z_1}}{V_{z_2}} \left[ 1.12 + 0.0117(i-i^*)^{1.43} + 0.61 \frac{\cos^2\beta_1}{\sigma} \left( \tan\beta_1 - \frac{V_{z2}}{V_{z1}} \tan\beta_2 \right) \right] \quad (2.2)$$

the equivalent diffusion ratio at the reference point can be obtained by setting $i=i^*$. Thus, Equation (2.1) can be rewritten as follows:

$$\begin{aligned} \delta-\delta^* = {} & 1.12k \, [(W_1/W_2) - (W_1/W_2)^*] \\ & + 0.0117 \, (i-i^*)^{1.43} \, k \, (W_1/W_2) \\ & + 0.61 \, k \, (\sin\varepsilon - \sin\varepsilon^*)/\sigma \end{aligned} \quad (2.3)$$

Assuming that the second and third terms on the right-hand side can be incorporated into the first term, one can write the following equation.

$$\delta-\delta^* = K \, [(W_2/W_1) - (W_2/W_1)^*] \quad (2.4)$$

where K is referred to as the deviation constant. The deviation constant can be related to the amount of diffusion in a blade passage in the case of gas (single phase) flow through a compressor. In the case of droplet-laden gas flow, it is assumed that the deviation constnt can still be related to the diffusion in a blade passage utilizing the water content in the mixture as a parameter. One can then obtain the deviation angle for given operating conditions and hence the corresponding blade outlet flow angle.

### 2.2.2 Correlations for Stage Pressure-Rise Coefficient

The stage pressure-rise coefficient for a compressor stage may be defined as follows.

$$\psi = \frac{\eta C_p \Delta T_o}{U^2}$$

where $\eta$ : stage adiabatic efficiency

$C_p$ : specific heat at constant pressure

$\Delta T_o$ : rise in stagnation temperature across a stage

$U$ : rotor whirl speed

The stage pressure-rise coefficient can be related to the stage flow coefficient utilizing water content.

### 2.2.3 Correlations for Efficiency

The adiabatic efficiency of the compression processes in a stage may be defined as follows:

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

where PR and TR are the stagnation pressure ratio and the stagnation temperature ratio across a stage, and $\gamma$ is the ratio of specific heats. The stage adiabatic efficiency can be related to the stage flow coefficient utilizing water content as the parameter.

### 2.2.4 Procedure for Obtaining Correlations for Deviation Angle, Pressure-Rise Coefficient and Efficiency

It is common practice in compressor analysis to obtain correlations for the deviation angle, pressure-rise coefficient and efficiency for different classes of blading through cascade or compressor tests.

Such correlations with respect to flow coefficient are well-known in literature for air or other (single-phase) gaseous fluids. Similar correlations are not available for droplet-laden flows from experimental results.

One method of generating such correlations is by the use of the PURDU-WICSTK Code. The performance of a series of typical compressors can be calculated utilizing that code and from such performance calculations, the variation of the parameters of interest can be extracted for different classes of blading in those compressors while operating with two-phase fluids. The parametric variations may then be related to blading design and operational conditions. Thus, based on the performance results obtained on any compressor utilizing the PURDU-WICSTK program over appropriate ranges of initial and operating conditions, one can generate correlations for deviation angle, pressure-rise coefficient and efficiency in terms of the following.

(i) Values of deviation constant, K, as a function of the diffusion of the working fluid;

(ii) Values of pressure-rise coefficient as a function of the flow coefficient; and

(iii) Values of efficiency as a function of the flow coefficient.

The correlations are obtained for each class of blading or stage with water content at entry to that blading or stage as one parameter and the operating speed as the other parameter. Those correlations can then be utilized in the NASA-WISGSK Code for obtaining the performance of a similar compressor under desired operating conditions. When a series of such correlations have been generated for various classes of blading and for various operating conditions, several classes of axial-flow compressors can be analyzed on this basis in order to determine changes in performance with water ingestion.

In order to illustrate the nature of correlations that can be obtained utilizing the PURDU-WICSTK program and that are suitable for incorporating into the NASA-WISGSK program, a series of correlations

have been obtained for the 6-stage axial-flow Test Compressor, referred to in Section 1.2 of the report, utilizing the PURDU-WICSTK program.

Some examples of such correlations have been obtained under the following conditions.

| | | |
|---|---|---|
| Operating speed | . . . | 90 percent design speed. |
| Droplet size | . . . | 600 μm (referred to as large). |
| Water content as mass fraction of water in the mixture | . . . | 0.000, 0.025, 0.075, 0.125, and 0.150. |

The correlations are presented in three parts, namely (i) for the deviation constant, (ii) for the pressure-rise coefficient and (iii) for the efficiency. In each case, the correlations have been given for different stages of the compressor. According to the basic design of the compressor, the type of blading employed in the different stages can be grouped as follows.

a) blading in stage 1;
b) blading in stage 2; and
c) blading in stages 3, 4, 5 and 6.

From the point of view of blade loading, it appears that it is necessary to distinguish further between stage 3 and stages 4, 5 and 6.

The correlations for <u>deviation constant</u> have been presented in the following figures.

Figure 4(a): Deviation constant vs $[(W_2/W_1) - (W_2/W_2)^*]$ (Stage 1)

Figure 4(b): Deviation constant vs $[(W_2/W_1) - (W_2/W_1)^*]$ (Stage 2)

Figure 4(c): Deviation constant vs $[(W_2/W_1) - (W_2/W_1)^*]$ (Stages 3, 4, 5, 6)

The correlations for pressure-rise coefficient corresponding to the afore-mentioned examples of correlations for the deviation constant have been presented in the following figures.

Figure 5(a): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 1)
Figure 5(b): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 2)
Figure 5(c): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 3)
Figure 5(d): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stages 4, 5, 6)

In these correlations, the stage pressure-rise coefficient and stage flow coefficient are normalized with respect to the design point values.

A set of examples of correlations for the adiabatic efficiency of different stages have been presented in the following figures. In all of the cases again only large droplets have been considered. The adiabatic efficiency is again normalized with respect to the design point value.

Figure 6(a): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 1)
Figure 6(b): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 2)
Figure 6(c): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stage 3)
Figure 6(d): $\psi/\psi^*$ vs $\phi/\phi^*$ (Stages 4, 5, 6)

It is of interest to observe the following from the correlations presented.

(i) The correlations for both K and $\eta$ show that there is some similarity in regard to their variation with water content in the entry mixture.

(ii) The variation of K with respect to diffusion is rather severe for flow diffusion values in the vicinity of the design point, especially at the higher values of water content in the entry mixture. At large values of diffusion, the water content does not seem to have a significant effect.

It is of importance to note that the nature of variations of K and $\eta$ may be different at other operating speeds. However, it is assumed

that such variations are small and that similar variations can be assumed over appropriate ranges of flow coefficients at other speeds. Nevertheless, the correlations presented should be considered as applicable only to the type of blading and blade-loading in the Test Compressor.

Other aspects of predictions of the Test Compressor performance utilizing the PURDU-WICSTK program can be found in References 6 and 7.

## 2.3 Modification of NASA-STGSTK Code to NASA-WISGSK Code for Use with Two-Phase Flow

The NASA-WISGSK Code for use with two-phase flow has been obtained by modifying the NASA-STGSTK Code in two respects.

(i) Introducing the stage characteristics for two-phase fluid flow in place of the stage characteristics utilized originally for air flow through the compressor; and

(ii) Incorporating various two-phase fluid associated processes at the stage exit in order to obtain the final state of the fluid at that location.

The principal stage characteristics are the efficiency and the pressure-rise coefficient. They are obtained at a reference operating speed, usually the design operating speed although another operating speed may be utilized.

The two-phase fluid flow effects of major interest are (i) the redistribution of water due to centrifugal action, (ii) the heat and mass transfer giving rise to a change in the temperature and mass fraction of the mixture constituents and (iii) the change in droplet size.

### 2.3.1. Efficiency Variation with Respect to Flow Coefficient

The reference curves for the variation of efficiency with respect to flow coefficient, obtained at the reference speed for various values

of water content in the entry mixture, for a particular compressor stage are adapted for use at other operating speeds in the NASA-WISGSK Code in two steps as follows.

(i) First, the reference curve for the case of air flow (and no water in the mixture) is shifted as illustrated in Figure 7 for use at the desired off-reference operating speed over the appropriate range of flow coefficient.

(ii) Next, the reference curve is modified for the presence of water following the correlations obtained for different water contents in the mixture at the reference speed. This part of the procedure is also illustrated in Figure 7.

### 2.3.2 Pressure-Rise Coefficient vs Flow Coefficiency

In the NASA-STGSTK Code, the pressure-rise coefficient is calculated in the subroutine CSPSI (Reference 3). In that subroutine, the pressure-rise coefficient is calculated based on the deflection of air flow over a rotor blade which in turn depends upon the blade outlet flow angle and hence the deviation angle. The blade deviation angle is estimated utilizing the following rule.

$$\delta-\delta^* = K\ [(W_2/W_1) - (W_2/W_1)^*]$$

with K = -10 for the case of air flow. In the case of operation with air-water mixture flow, the deviation constant, K, is a function of water content and amount of diffusion.

Utilizing the appropriate values of K, based, for example, upon the type of correlations presented in Figure 4, the pressure-rise coefficient can be obtained at the reference speed and at off-design speeds for various values of water content in the entry mixture as a function of flow coefficient.

### 2.3.3 Correction for Two-Phase Effects

The NASA-WISGSK Code incorporates the following new features in order to correct the blade outlet conditions that are obtained based upon stage characteristics for the following two-phase fluid flow effects:

(i) droplet size adjustment;
(ii) centrifugal force action; and
(iii) heat and mass transfer.

The details regarding modelling of these processes can be found in Reference 5.

## 2.4 The General Procedure for Utilization of the NASA-WISGSK Code

It is expected that for the compressor under consideration, the following stage characteristics are available for each stage of the compressor at a convenient reference speed over a range of mass flows.

(i) Adiabatic efficiency as a function of gas phase flow coefficient for various values of mass fraction of water in the mixture; and
(ii) Deviation factor as a function of diffusion of the working fluid for various values of mass fraction of water in the mixture.

Utilizing the latter, the pressure-rise coefficient characteristics for different stages can be obtained as a function of flow coefficient utilizing the mass fraction of water in the entry mixture as a parameter.

As stated earlier (Section 2.3.1) the efficiency curves may need to be shifted for use at off-reference operating speeds. The pressure-rise coefficient characteristics are treated as applicable at all values of operating speed, at least over a substantial range of speeds.

It can be visualized that the efficiency and the pressure-rise coefficient characteristics may be available at discrete values of mass fraction of water. Since the mass fraction of water changes along a compressor flow path in different ways along different streamlines, it is useful to devise rules for interpolating the stage characteristics for various values of mass fraction of water.

The water vapor in the mixture at entry to a compressor stage is taken into account in the form of mass fraction of vapor for the purposes of determining the thermodynamic properties as a part of the gas phase in the mixture.

The initial and operating conditions to be specified in utilizing the NASA-WISGSK Code are the following:

(i) the operating speed;

(ii) the mixture mass flow;

(iii) the mixture composition including the droplet size; and

(iv) the ambient conditions in the mixture entering the compressor.

The calculation procedure may then be divided into three parts as follows:

(i) calculation of performance of compressor at reference and off-reference speeds with air flow only;

(ii) calculation of performance of compressor at reference speed and different values of mass flows with various values of water content; and

(iii) calculation of performance of compressor at off-reference speeds with various values of mixture flows and mass fractions of water.

In each case, calculations may be performed along any streamtube selected in the compressor with specified (a) mass flow and mixture composition at entry, (b) area change and (c) work input at appropriate rotor locations. It may be recalled that the calculation procedure is based on a one-dimensional formulation.

### 2.4.1 Calculation with Air Flow

The performance calculation with air flow at the reference and the off-reference speeds is intended to establish (a) the extent to which the stage efficiency curve needs to be adjusted by shifting over the desired range of flow coefficient (utilizing the procedure described in Section 2.3.1) and (b) the ranges of flow coefficient that can be covered in the performance calculation at different operating speeds utilizing the available stage characteristics. When the compressor performance is available from another source at different operating speeds, one can compare such performance parameter values with those obtained utilizing the NASA-WISGSK Code. Utilizing a trial-and-error procedure, any small differences in performance at off-reference speeds can be adjusted through modifying the stage characterisitics available at the reference speed for various off-reference speeds. However, such modifications need to be introduced with considerable judgement.

The calculation procedure for given (a) ambient conditions, (b) operating speed and (c) air mass flow may be summarized as follows.

(i) The flow coefficient is determined at the compressor inlet.

(ii) The stage efficiency can be obtained directly from the efficiency vs flow coefficient curve for the stage when the operating speed under consideration is the same as the reference speed. If the operating speed is different from the reference speed, the efficiency-flow coefficient curve has to be shifted appropriately (Section 2.3.1) and the efficiency then obtained for the value of flow coefficient specified.

(iii) The stage pressure-rise coefficient characteristic is utilized for obtaining the value of pressure-rise coefficient at the specified value of flow coefficient.

(iv) The stage pressure ratio and temperature ratio are calculated as follows:

$$PR = 1.0 + \frac{U^2}{c_p T_{o1}} \psi$$

$$TR = 1.0 + (PR^{\gamma-1/\gamma} - 1.0)\ \eta$$

(v) The resulting stage outlet conditions become the inlet conditions for the next stage, if any. The procedure given under items (i) to (iv) is then repeated for each of the stages until the compressor outlet station is reached.

(vi) The performance of each stage of the compressor as well as the overall performance of the compressor can then be obtained from the predictions for the given operating conditions.

(vii) The entire procedure may be repeated at the desired operating speeds and mass flows.

### 2.4.2 Calculation with Air-Water Mixture Flow at Reference Speed

At the reference speed, the available stage characteristics (pertaining to efficiency and pressure-rise coefficient) are usable directly.

The procedure for calculation of performance at various values of mixture mass flow (or gas phase flow coefficient and liquid phase mass fraction) is identical to that described in Section 2.4.1 except for the following: (i) the efficiency and pressure-rise coefficient values should be chosen for the local value of water content in the entry mixture for each stage and (ii) the stage outlet conditions have to be corrected for two-phase flow effects.

The primary purpose of the calculation of performance at the reference speed is to establish the applicability of the available

stage characteristics for the ranges of water content that are likely to arise in different stages under different conditions. Since centrifugal action is only a function of the rotation in the flow field, by performing calculations at the reference operating speed, the effect of water content and the applicability of the available stage characteristics can be examined in the different stages of a compressor. If the general trend of performance changes is acceptable, the pressure-rise coefficient information can be utilized with some confidence at off-reference speeds.

### 2.4.3 Calculation with Air-Water Mixture Flow under General Conditions of Operation

At off-reference operating speeds, the efficiency-flow coefficient curves need to be shifted to become applicable over the relevant range of flow coefficient in each stage of a compressor.

The calculation procedure for obtaining the performance is then identical to that described in Section 2.4.1 except for the following: (i) the efficiency and pressure-rise coefficient values should be chosen for the local values of water content in the entry mixture for each stage, (ii) the efficiency curves should be moved as required to become applicable over the relevant range of flow coefficient at the operating speed specified and (iii) the correction of stage outlet conditions for two-phase flow effects.

The stage outlet conditions are corrected for the following effects associated with two-phase flow:

a) Droplet size adjustment;
b) Centrifugal force action; and
c) Heat and mass transfer.

The stage outlet conditions are then obtained in terms of mixture composition, gas phase properties and liquid phase properties, including the droplet size.

# CHAPTER III

## SUBROUTINES AND EXTERNAL FUNCTIONS

The following is the list of subroutines and external functions used in the NASA-WISGSK code. The subroutines and external functions consist of two parts as follows: Part I of the subroutines and external functions is the same as those in PURDU-WICSTK code (Reference 5) and Part II of the subroutines and external functions closely follows those in NASA-STGSK code (Reference 3). Only brief descriptions of these subprograms are given here. A more detailed description of each subprogram is presented in Appendix 3.

### PART I

Subroutine WICSPC: calculation of stage performance based on the analytical/correlation method for large droplet.

Subroutine WICSPD: calculation of design point performance.

Subroutine WICSCC: calculation of the equivalent pressure ratio, equivalent temperature rise ratio, and stage adiabatic efficiency for a particular stage based on the inputed stage characteristic curves.

Subroutine WICGSL: calculation of single-phase (gas) flow loss.

Subroutine WICSDL: calculation of loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets.

Subroutine WICSTL: calculation of loss due to Stokesian drag of large droplets in the free stream of blade passage.

Subroutine WICFML: calculation of loss due to film formed on blade surface when large droplets are present either by themselves or along with small droplets.

Subroutine WICRSL: calculation of loss due to the rough surface when large droplets are present either by themselves or along with small droplets.

Subroutine WICVT: calculation of components of velocity triangle and angles.

Subroutine WICCEN: calculation of swanwise displacement of droplets due to centrifugal action.

Subroutine WICDMS: calculation of amount of small droplets which are centrifuged.

Subroutine WICDML: calculation of amount of large droplets which are centrifuged.

Subroutine WICDRG: calculation of drag force on large droplet.

Subroutine WICMAC: calculation of Mach number.

Function WICASD: calculation of acoustic speed in two phase flow.

Subroutine WICBOA: calculation of blade outlet angle.

Subroutine WICEDD: calculation of equivalent diffusion at design point.

Function WICED: calculation of equivalent diffusion.

Function WICMTK: calculation of dimensionless momentum thickness.

Function WICLOS: calculation of total pressure loss coefficient.

Subroutine WICIRS: calculation of droplet impingement and rebound in rotor for small droplet.

Subroutine WICIRL: calculation of droplet impingement and rebound in rotor for large droplet.

Subroutine WICISS: calculation of droplet impingement and rebound in stator for small droplet.

Subroutine WICISL: calculation of droplet impingement and rebound in stator for large droplet.

Subroutine WICWAK: calculation of water reingestion into wake.

Subroutine WICHET: calculation of heat transfer between gaseous phase and droplets.

Subroutine WICMAS: calculation of mass transfer between gaseous phase and droplets.

Function WICMTR: calculation of mass transfer rate.

Function WICPWB: calculation of vapor pressure.

Function WICNEW: calculation of new trial value in the interative procedure.

Function WICTAN: calculation of the value of tangent function.

Function WICBPT: calculation of boiling point.

Function WICSH: calculation of specific humidity.

Subroutine WICSIZ: calculation of nominal droplet size.

Subroutine WICPRP: calculation of flow properties for gaseous phase.

Function WICCPA: calculation of specific heat at constant pressure for air.

Function WICCPH: calculation of specific heat at constant pressure for vapor.

Function WICCPC: calculation of specific heat at constant pressure for methane.

PART II

Subroutine NASA: subroutine which corresponds to MAIN program of NASA-STGSTK code.

Subroutine CSINPT: reads and writes the Part II of input data.

Subroutine CSPREF: calculates parameters at design speed and design flow conditions.

Function CPFM: calculates specific heat at constant pressure from static temperature using fifth degree polynomial.

Subroutine CSETA: calculates adiabatic efficiency versus flow coefficient.

Subroutine CSPSI: calculates pressure coefficients for inputed flow coefficients

Subroutine CSDEVS: calculates stator deviation angle for small droplet calculation.

Subroutine CDEVSL: calculates stator deviation angle for large droplet calculation.

Subroutine CSDEV: calculates rotor deviation angle for small droplet calculation.

Subroutine CSDEVL: calculates rotor deviation angle for large droplet calculation.

Subroutine CSETA1: calculates adiabatic efficiency for small droplet calculation.

Subroutine CSETAL: calculates adiabatic efficiency for large droplet calculation.

Subroutine CSPSD: alters pressure coefficient for off design speeds.

Subroutine CSPAN: alters flow coefficient and pressure coefficient for blade reset.

Subroutine CSOUPT: calculates and prints out stage performance for small droplet calculation.

Subroutine COUPTZ: calculates and prints out stage performance for large droplet calculation.

Function DELK70: alters diffusion constant for 70% rotor speed.

Function DELK80: alters diffusion constant for 80% rotor speed.

Function DELK10: alters diffusion constant for 100% rotor speed.

Function DPHI: alters flow coefficient for different rotational speed.

# CHAPTER IV

# INPUT DATA

The following is a list of the input data as they are read in the NASA-WISGSK code. All input data that are needed to use the code are described herein. The input data consist of two parts as follows: Part I of the input data is the same as those in the PURDU-WICSTK code (Reference 5), and Part II of the input data follow very closely those in the NASA-STGSTK code (Reference 3).

## PART I

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 1 | NS | number of stage | I1 |
| 2 | RRHUB(I) | hub radius at Ith stage rotor inlet. I = 1 $\sim$ NS<br>Unit: inch or cm | F 5.3 |
| 3 | RC(I) | chord length of Ith stage rotor<br>I = 1 $\sim$ NS<br>Unit: inch or cm | F 5.3 |
| 4 | RBLADE(I) | number of blade for Ith stage rotor. I = 1 $\sim$ NS | F 5.2 |
| 5 | STAGER(I) | staggerangle for Ith stage rotor<br>I = 1 $\sim$ NS<br>Unit: degree | F 5.2 |
| 6 | SRHUB(I) | hub radius at Ith stage stator inlet.<br>I = 1 $\sim$ NS, I = NS + 1 for IGV<br>Unit: inch or cm | F 5.3 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 7 | SC(I) | chord length of Ith stage stator<br>I = 1 ∿ NS, 1 = NS + 1 for IGV<br>Unit: inch or cm | F 5.3 |
| 8 | SBLADE(I) | number of blade for Ith stage stator.<br>I = 1 ∿ NS, I = NS + 1 for IGV | F 5.2 |
| 9 | SIGUMR(I) | solidity of Ith stage rotor<br>I = 1 ∿ NS | F 5.3 |
| 10 | SIGUMS(I) | solidity of Ith stage stator<br>I = 1 ∿ NS, I = NS + 1 for IGV | F 5.3 |
| 11 | BET2SS(I) | absolute flow angle at Ith stage stator outlet<br>I = 1 ∿ NS, I = NS + 1 for IGV | F 5.2 |
| 12 | FNF | fraction of design corrected rotor speed for a particular speed | F 8.2 |
| 13 | XDIN | initial water content (mass fraction) of small droplet | F 5.3 |
| 13 | ICENT | index for centrifugal calculation of small droplet<br>ICENT = 1 when XDIN = 0.0<br>otherwise ICENT = 2 | I1 |
| 13 | XDDIN | initial water content (mass fraction) of large droplet | F 5.3 |
| 13 | IICNET | index for centrifugal calculation of large droplet<br>IICENT = 1 when IDDIN = 0.0<br>otherwise IICENT = 2 | I1 |
| 14 | TOG | total temperature of gas phase at compressor inlet<br>Unit: Rankine orKelvin | F 7.2 |
| 14 | TOW | temperature of droplet at compressor inlet<br>Unit: Rankine orKelvin | F 7.2 |

(continued)

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 14 | PO | total pressure at compressor inlet<br>Unit: $lbf/ft^2$ or $N/m^2$ | F 7.2 |
| 15 | DIN | initial diameter of small droplet<br>Unit: µm | F 6.1 |
| 15 | DDIN | initial diameter of large droplet<br>Unit: µm | F 6.1 |
| 16 | FND | rotor corrected speed at design point<br>Unit: RPM | F 7.1 |
| 16 | T01D | compressor inlet temperature at design point<br>Unit: Rankine or Kelvin | F 7.2 |
| 16 | P01D | compressor inlet pressure at design point<br>Unit: $lbf/ft^2$ or $N/m^2$ | F 7.2 |
| 17 | XCH4 | initial methane content (mass fraction) | F 5.3 |
| 17 | RHUMID | initial relative humidity<br>Unit: per cent | F 10.5 |
| 18 | FMWA | molecular weight of air | F 7.3 |
| 18 | FMWV | molecular weight of steam | F 7.3 |
| 18 | FMWC | molecular weight of methane | F 7.3 |
| 19 | PREB | percent of water droplet that rebound after impingement on blade surface | F 5.1 |
| 19 | DLIMIT | maximum diameter for small droplet<br>Unit: µm | F 7.1 |
| 20 | STAGES(I) | stagger angle for Ith stage stator<br>$I = 1 \sim NS$, $I = NS + 1$ for IGV<br>Unit: degree | F 5.2 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 21 | GAPR(I) | gap between Ith stage rotor and (I - 1)th stage stator<br>I = 1 ∿ NS<br>Unit: inch or cm | F 7.5 |
| 22 | GAPS(I) | gap between rotor blade and stator blade for Ith stage<br>I = 1 ∿ NS<br>Unit: inch or cm | F 7.5 |
| 23 | RRTIP(I) | blade tip radius at Ith stage rotor inlet<br>I = 1 ∿ NS<br>Unit: inch or cm | F 6.3 |
| 24 | SRTIP(I) | blade tip radius at Ith stage stator inlet<br>I = 1 ∿ NS<br>Unit: inch or cm | F 6.3 |
| 25 | IRAD | index for radius at which calculation is carried out<br>IRAD = 1: performance at tip<br>IRAD = 2: performance at mean<br>IRAD = 3. performance at hub | I1 |
| 26 | RT(I) | rotor inlet radius at which tip performance calculation is carried out<br>I = 1 ∿ NS<br>Unit: inch or cm | F 5.3 |
| 27 | RM(I) | rotor inlet radius at which mean line performance calculation is carried out<br>I = 1 ∿ NS<br>Unit: inch or cm | F 5.3 |
| 28 | RH(I) | rotor inlet radius at which hub performance calculation is carried out<br>I = 1 ∿ NS<br>Unit: inch or cm | F 5.3 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 29 | ST(I) | stator inlet radius at which tip performance calculation is carried out<br>I = 1 ∿ NS<br>Unit: inch or cm | F 5.3 |
| 30 | SM(I) | stator inlet radius at which mean line performance is carried out<br>I = 1 ∿ NS<br>Unit: inch or cm | F 5.3 |
| 31 | SH(I) | stator inlet radius at which hub performance calculation is carried out<br>I = 1 ∿ NS<br>Unit: inch or cm | F 5.3 |
| 32 | BLOCK(I) | blockage factor for Ith stage rotor<br>0<BLOCK(I)<1 | F 5.3 |
| 33 | BLOCKS(I) | blockage factor for Ith stage stator<br>0<BLOCKS(I)<1 | F 5.3 |
| 34 | BET1MR(I) | blade metal angle at Ith stage rotor inlet<br>Unit: degree | F 5.2 |
| 35 | BET2MR(I) | blade metal angle at Ith stage rotor outlet<br>Unit: degree | F 5.2 |
| 36 | BET1MS(I) | blade metal angle at Ith stage stator inlet<br>Unit: degree | F 5.2 |
| 37 | BET2MS(I) | blade metal angle at Ith stage stator outlet<br>Unit: degree | F 5.2 |
| 38 | DSMASS | mass flow rate at design point<br>Unit: $lb_m$/s or kg/s | F 10.6 |
| 39 | PR12D | total pressure ratio for the Ith stage rotor at design point | F 5.3 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 40 | PR13D | total pressure ratio for Ith stage | F 5.3 |
| 41 | ETARD(I) | adiabatic efficiency for Ith stage rotor | F 5.3 |
| 42 | SAREA(I) | stream tube area Ith stage rotor inlet Unit: $ft^2$ or $m^2$ | F 10.7 |
| 43 | SAREAS(I) | stream tube area for Ith stage stator inlet Unit: $ft^2$ or $m^2$ | F 10.7 |
| 44 | XBLEED(I) | amount of bleed at Ith stage outlet | F 5.2 |

PART II

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 45 | TITLE | title card on which any alphabetical data can be used | 12A6 |
| 46 | STAGEN | the number of stages | F 10.0 |
| 46 | SPEEDN | always 1.0 | F 10.0 |
| 46 | CHAPTS | number of points used to describe the stage characteristic | F 10.0 |
| 46 | PO | compressor inlet total pressure Unit: $lb_f/ft^2$ | F 10.0 |
| 46 | TO | compressor inlet total temperature Unit: Rankine | F 10.0 |
| 46 | DESRPM | design rotative speed Unit: RPM | F 10.0 |
| 46 | DESFLO | design flow rate Unit: $lb_m/sec$ | F 10.0 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 47 | WTMOLA | molecular weight of air | F 10.0 |
| 47 | WTMOLM | molecular weight of methane | F 10.0 |
| 47 | WTMOLS | molecular weight of steam | F 10.0 |
| 47 | XAR | mass fraction of dry air | F 10.0 |
| 47 | XMET | mass fraction of methane | F 10.0 |
| 47 | XSTM | mass fraction of steam | F 10.0 |
| 48 | SPDPSI | index to alter pressure coefficient for off-design speed. Pressure coefficient is altered for off-design speed if SPDPSI = 1.0; otherwise not. | F 10.0 |
| 48 | SPDPHI | index to alter flow coefficient for off-design speed. Flow coefficient is altered for off-design speed if SPDPHI = 1.0; otherwise not. | F 10.0 |
| 48 | DRDEVG | index to alter rotor deviation angle for blade reset. Rotor deviation angle is altered for blade reset if DRDEVG = 1.0; otherwise not. | F 10.0 |
| 48 | DRDEVN | index to alter rotor deviation angle for off-design speed. Rotor deviation angle is altered for off-design speed if DRDEVN = 1.0; otherwise not. | F 10.0 |
| 48 | DRDEVP | index to alter rotor deviation angle for off-design flow coefficient. Rotor deviation is altered for off-design flow coefficient if DRDEVP = 1.0; otherwise not. | F 10.0 |
| 48 | UNITS | always 0.0 | F 10.0 |
| 49 | CPCO(I) | coefficients for polynomial of specific heat at constant pressure for air | F 10.0 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 50 | CPCM(I) | coefficients for polynomial of specific heat at constant pressure for methane | F 10.0 |
| 51 | CPCS(I) | coefficients for polynomial of specific heat at constant pressure for steam | F 10.0 |
| 52 | RT2(I) | rotor inlet tip radius at Ith stage<br>Unit: inch | F 10.0 |
| 53 | RH2(I) | rotor inlet hub radius at Ith stage<br>Unit: inch | F 10.0 |
| 54 | RT3(I) | rotor outlet tip radius at Ith stage<br>Unit: inch | F 10.0 |
| 55 | RH3(I) | rotor outlet hub radius at Ith stage<br>Unit: inch | F 10.0 |
| 56 | BET2M(I) | rotor inlet absolute flow angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |
| 57 | CB2M(I) | change in rotor inlet absolute flow angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |
| 58 | CB2MR(I) | change in rotor inlet relative flow angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |
| 59 | CB3MR(I) | change in rotor outlet relative flow angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |
| 60 | RK2M(I) | rotor inlet blade metal angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |

| Card No. | Input Data | Comment | Format |
|---|---|---|---|
| 61 | RK3M(I) | rotor outlet blade metal angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |
| 62 | RSOLM(I) | rotor blade row solidity at Ith stage | F 10.0 |
| 63 | SK2M(I) | stator inlet blade metal angle at mean line radius at Ith stage<br>Unit: degree | F 10.0 |
| 64 | PR(I) | stage pressure ratio at design point for Ith stage | F 10.0 |
| 65 | ETAINP(I) | stage adiabatic efficiency at design point for Ith stage | F 10.0 |
| 66 | PHIINP(I) | flow coefficient at design stage for Ith stage | F 10.0 |
| 67 | PCTSPD | value of rotative speed expressed as a decimal fraction of design speed | F 10.0 |
| 68 | ETARAT | ratio of adiabatic efficiency at design speed to adiabatic efficiency at speed corresponding to PCTSPD | F 10.0 |
| 69 | BLEED | amount of bleed<br>Unit: $lb_m/sec$ | F 10.0 |
| 70 | PHIDES | stage flow coefficient at design speed | F 10.0 |
| 71 | PSIDES | stage pressure coefficient at design speed, when input PR is not zero, then PSIDES must be zero | F 10.0 |
| 72 | ETADES | stage adiabatic efficiency at design speed, when input ETAINP is not zero, then ETADES must be zero | F 10.0 |
| 73 | FAI(K) | initial flow coefficient<br>K = 1 $\sim$ CHAPTS<br>one value per one card | F 7.5 |

# CHAPTER V

# OUTPUT

The output generated utilizing the NASA-WISGSK code is described here. The output consists of five parts as follows:

(1) output of the input data;
(2) output of design point performance;
(3) output of stage characteristic;
(4) output of stage performance; and
(5) output of overall performance.

These five parts are described in the following.

## 5.1 Output of Inputed Data

All of the data inputed can be printed out at the beginning of output.

## 5.2 Output of Design Point Performance

### 5.2.1 Compressor Inlet (Design Point Performance)

At the compressor inlet, the following properties can be printed out for the design point performance:

(1) total temperature at compressor inlet: (R) or (K)
(2) total pressure at compressor inlet: ($lbf/ft^2$) or ($N/m^2$)
(3) static temperature at compressor inlet: (R) or (K)
(4) static pressure at compressor inlet: ($lbf/ft^2$) or ($N/m^2$)
(5) static density at compressor inlet: ($lbm/ft^3$) or ($kg/m^3$)
(6) acoustic speed at compressor inlet: (ft/s) or (m/s)
(7) axial velocity at compressor inlet: (ft/s) or (m/s)

(8) Mach number at compressor inlet
(9) stream tube area at compressor inlet: ($ft^2$) or ($m^2$)
(10) flow coefficient at compressor inlet

### 5.2.2 Stage Performance (Design Point Performance)

At the end of each stage, the following properties can be printed out for the design point performance:

(1) total temperature: (R) or (K)
(2) total pressure: ($lbf/ft^2$) or ($N/m^2$)
(3) static temperature: (R) or (K)
(4) static pressure: ($lbf/ft^2$) or ($N/m^2$)
(5) static density: ($lbm/ft^3$) or ($kg/m^3$)
(6) axial velocity: (ft/s) or (m/s)
(7) absolute velocity: (ft/s) or (m/s)
(8) relative velocity: (ft/s) or (m/s)
(9) tangential component of absolute velocity: (ft/s) or (m/s)
(10) tangential component of relative velocity: (ft/s) or (m/s)
(11) rotor wheel speed: (ft/s) or (m/s)
(12) absolute Mach number
(13) relative Mach number
(14) total temperature based on relative Mach number: (R) or (K)
(15) total pressure based on relative Mach number: ($lbf/ft^2$) or ($N/m^2$)
(16) absolute flow angle: (degree)
(17) relative flow angle: (degree)
(18) stream tube area: ($ft^2$) or ($m^2$)
(19) radius at which calculation is carried out: (ft) or (m)
(20) flow coefficient
(21) stage total pressure ratio
(22) stage adiabatic efficiency
(23) rotor total pressure ratio
(24) rotor adiabatic efficiency
(25) stage total temperature ratio

### 5.2.3 Overall Performance (Design Point Performance)

After all of stage performance is printed out, the following properties can be printed out:

(1) compressor inlet total temperature: (R) or (K)
(2) compressor inlet total pressure: ($lbf/ft^2$) or ($N/m^2$)
(3) corrected mass flow rate: (lbm/s) or (kg/s)
(4) overall total pressure ratio
(5) overall total temperature ratio
(6) overall adiabatic efficiency
(7) overall temperature rise: (F) or (C)
(8) relative flow angle at rotor inlet: BET1SR(I) (degree)
(9) relative flow angle at rotor outlet: BET2SR(I) (degree)
(10) incidence for rotor: AINCSR(I) (degree)
(11) deviation for rotor: ADEVSR (degree)
(12) absolute flow angle for stator inlet: BET1SS(I) (degree)
(13) absolute flow angle for stator outlet: BET2SS(I) (degree)
(14) incidence for stator: AINCSS(I) (degree)
(15) deviation for stator: ADEVSS(I) (degree)
(16) stage inlet temperature: TD(I) (R) or (K)
(17) total pressure loss coefficient for stator: OMEGS(I)
(18) total pressure loss coefficient for rotor: OMEGR(I)

## 5.3 Output of Stage Characteristics

The inputed and/or computed stage characteristic can be printed out. The flow coefficient, pressure coefficient and adiabatic efficiency for each stage are printed out. This part of output is the same as one in NASA-SGSTK code (Reference 3).

## 5.4 Output of Stage Performance

The performance of a stage is calculated for given initial and operating conditions with respect to the gaseous phase and the water droplets. At the exit of a blade row, the four major processes

associated with two phase flow, namely (a) droplet impingement process; (b) centrifugal action on droplets; (c) heat and mass transfer processes between the two phases; and (d) droplet size adjustment are taken into account. When the stage performance parameters are corrected for the afore-mentioned four processes, then one obtains the outlet conditions from a stage. The output of stage performance consist of two parts. First the following properties can be printed out before the afore-mentioned four processes are taken into account:

(1) stage total pressure ratio
(2) stage total temperature ratio
(3) stage adiabatic efficiency
(4) stage flow coefficient
(5) axial velocity: (ft/sec) or (m/sec)
(6) rotor speed: (ft/sec) or (m/sec)
(7) total pressure: ($lbf/ft^2$) or ($N/m^2$)
(8) static pressure: ($lbf/ft^2$) or ($N/m^2$)
(9) total temperature of gas phase: (R) or (K)
(10) static temperature of gas phase: (R) or (K)
(11) static density of gas phase: ($lbm/ft^3$) or ($kg/m^3$)
(12) static density of mixture: ($lbm/ft^3$) or ($kg/m^3$)
(13) axial velocity: (ft/s) or (m/s)
(14) absolute velocity: (ft/s) or (m/s)
(15) relative velocity: (ft/s) or (m/s)
(16) blade wheel speed: (ft/s) or (m/s)
(17) tangential component of absolute velocity: (ft/s) or (m/s)
(18) tangential component of relative velocity: (ft/s) or (m/s)
(19) acoustic speed: (ft/sec) or (m/s)
(20) absolute Mach number
(21) relative Mach number
(22) flow coefficient
(23) stream tube area ($ft^2$) or ($m^2$)
(24) absolute flow angle: (degree)
(25) relative flow angle: (degree)
(26) incidence: (degree)
(27) deviation: (degree)

After the stage parameters are corrected for the afore-mentioned four processes, the following second part of output of stage performance can be printed out:

(1) stage total pressure ratio

(2) stage total temperature ratio

(3) stage adiabatic efficiency

(4) water vapor content: XV

(5) water content of small droplet: XW

(6) water content of large droplet: XWW

(7) total water content: XWT

(8) mass fraction of dry air: XAIR

(9) mass fraction of methane: XMETAN

(10) mass fraction of gaseous phase: XGAS

(11) mass flow rate of small droplet: WMASS (lbm/s) or (Kg/S)

(12) mass flow rate of large droplet: WWMASS (lbm/s) or (Kg/S)

(13) total mass flow rate of droplet: WTMASS (lbm/s) or (Kg/S)

(14) mass flow rate of dry air: AMASS (lbm/s) or (Kg/S)

(15) mass flow rate of methane: CHMASS (lbm/s) or (Kg/S)

(16) mass flow rate of water vapor: VMASS (lbm/s) or (Kg/S)

(17) mass flow rate of gaseous phase: GMASS (lbm/s) or (Kg/S)

(18) mass flow rate of mixture: TMASS (lbm/s) or (Kg/S)

(19) specific humidity: WS

(20) density of air: RHOA (lbm/$ft^3$) or (Kg/$m^3$)

(21) density of mixture: RHOM (lbm/$ft^3$) or (Kg/$m^3$)

(22) density of gaseous phase: RHOG (lbm/$ft^3$) or (Kg/$m^3$)

(23) temperature of gaseous phase: TG (R) or (K)

(24) temperature of small droplet: TW (R) or (K)

(25) temperature of large droplet: TWW (R) or (K)

(26) pressure: P (lbf/$ft^2$) or (N/$m^2$)

(27) boiling point: TB (R) or (K)

(28) dew point: TDEW (R) or (K)

## 5.5 Output of Overall Performance

At the end of compressor, the overall performance can be printed out. The properties to be printed out are as follows:

(1) initial flow coefficient

(2) corrected speed of compressor and fraction of design corrected speed

(3) initial water content of small droplet

(4) initial water content of large droplet

(5) initial total water content

(6) initial relative humidity

(7) initial methane content

(8) compressor inlet total temperature: (R) or (K)

(9) compressor inlet total pressure: ($lbf/ft^2$) or ($N/m^2$)

(10) corrected mass flow rate of mixture: (lbm/s) or (Kg/S)

(11) corrected mass flow rate of gaseous phase: (lbm/s) or (Kg/S)

(12) overall total pressure ratio

(13) overall total temperature ratio

(14) overall adiabatic efficiency

(15) overall temperature rise of gaseous phase: (F) or (C)

# CHAPTER VI

## TEST CASE AND DISCUSSION

The performance calculation procedure is illustrated in the case of the Test-Compressor (referred to in Section 1.2) utilizing the correlations of performance parameters presented in Section 2.2 and the procedure for performance calculation presented in Sections 2.3 and 2.4.

The detailed printout of the input and output of the NASA-WISGSK Code is presented in Appendix 4 for the following two cases at a chosen value of inlet flow coefficient.

1) Test Case No. 1: Operation with air flow at 100 percent of the design speed at the meanline section of the compressor.
2) Test Case No. 2: Operation with air-water mixture containing large droplets (with a mass fraction of 0.040 of water) at 100 percent of design speed at the meanline section of the compressor.

Utilizing the same procedure, the performance of the Test Compressor has been determined at a number of operating conditions given in Table 2. The results of performance calculations have been presented in the following figures.

Figure 8(a): Overall stagnation pressure ratio as a function of gas phase corrected mass flow rate at tip section.

Figure 8(b): Overall stagnation temperature ratio as a function of gas phase corrected mass flow rate at tip section.

## 6.1 Discussion

The NASA-WISGSK Code provides a means of calculating the overall performance of an axial-flow compressor with water ingestion at selected spanwise sections utilizing a one-dimensional calculation procedure. The principal inputs to the Code are the following at a particular spanwise section.

(i) The design point details of the compressor; and

(ii) The stage characteristics at a selected speed of operation with air flow and air-water mixture flow, the latter over the desired range of water mass fraction in the mixture.

The stage characteristics are then approximated at other values of operating speed and at other spanwise sections.

During the calculations of performance for the cases given in Table 2, the stage characteristics have been assumed for operation at 90 percent design speed and at the meanline section of the compressor. It can be seen from Figures 11(a) and 11(b) that the meanline predicted performance for the case of operation with air flow at 90 and 80 percent design speed values corresponds very nearly to the experimental data (Reference 6) obtained at that spanwise section and speed. At 100 percent design speed, it can be observed from the same figure that some difference arises between predictions and experimental data, although the general trend of performance is obtained qualitatively correctly.

By means of a trial and error procedure for adaptation of stage characteristics for each of the stages in the compressor, it is possible to obtain a prediction that is close to experimental data to any desired degree of agreement at any speed and at any section of the compressor. However, this involves considerable empiricism in the adaptation of stage characteristics for different operating conditions at different spanwise sections.

TABLE 2

Operating Conditions of Test Compressor
(Utilized in the Illustration of
Performance Calculation Procedure)

| Parameter | Range of Values |
|---|---|
| 1) Compressor speed | 80, 90 and 100% design speed |
| 2) Mass fraction of water in the mixture | 0.000, 0.030, 0.040, 0.080 and 0.150 |
| 3) Mixture mass flow rates | At least five values at each speed |

During water ingestion, the basic performance of a stage is again obtained in the NASA-WISGSK Code utilizing the stage characteristics estimated for one selected speed and one spanwise section at all other speeds and spanwise sections. Thus only the general trends in performance changes can be established.

A further limitation of the NASA-WISGSK Code procedure is that the ranges of mixture mass flow and water mass fraction over which predictions can be obtained become restricted to different extents at different speeds and at different spanwise sections. Thus, in the present case, the stage characteristics with water ingestion are estimated first at 90 percent design speed and at the tip section. They are then adapted for use at other speeds and spanwise sections. It is then found that depending upon the mass fraction of water at the entry section of the compressor the prediction of performance at the tip section for high water mass fraction values at a higher operating speed (say, 100 percent design speed) may only be carried out for a small range of mixture mass flows, considerably less than, for example, at the mean and hub sections of the compressor.

It may be pointed out that no general conclusions may be drawn at this stage of utilization of the Code regarding its applicability to various compressors of different design and operating conditions. At the same time, it is clear that (a) the trend of performance changes can be established utilizing the Code and (b) the limitations in applicability arise in regard to the ranges of (i) speed, (ii) mixture mass flow and (iii) water mass fraction.

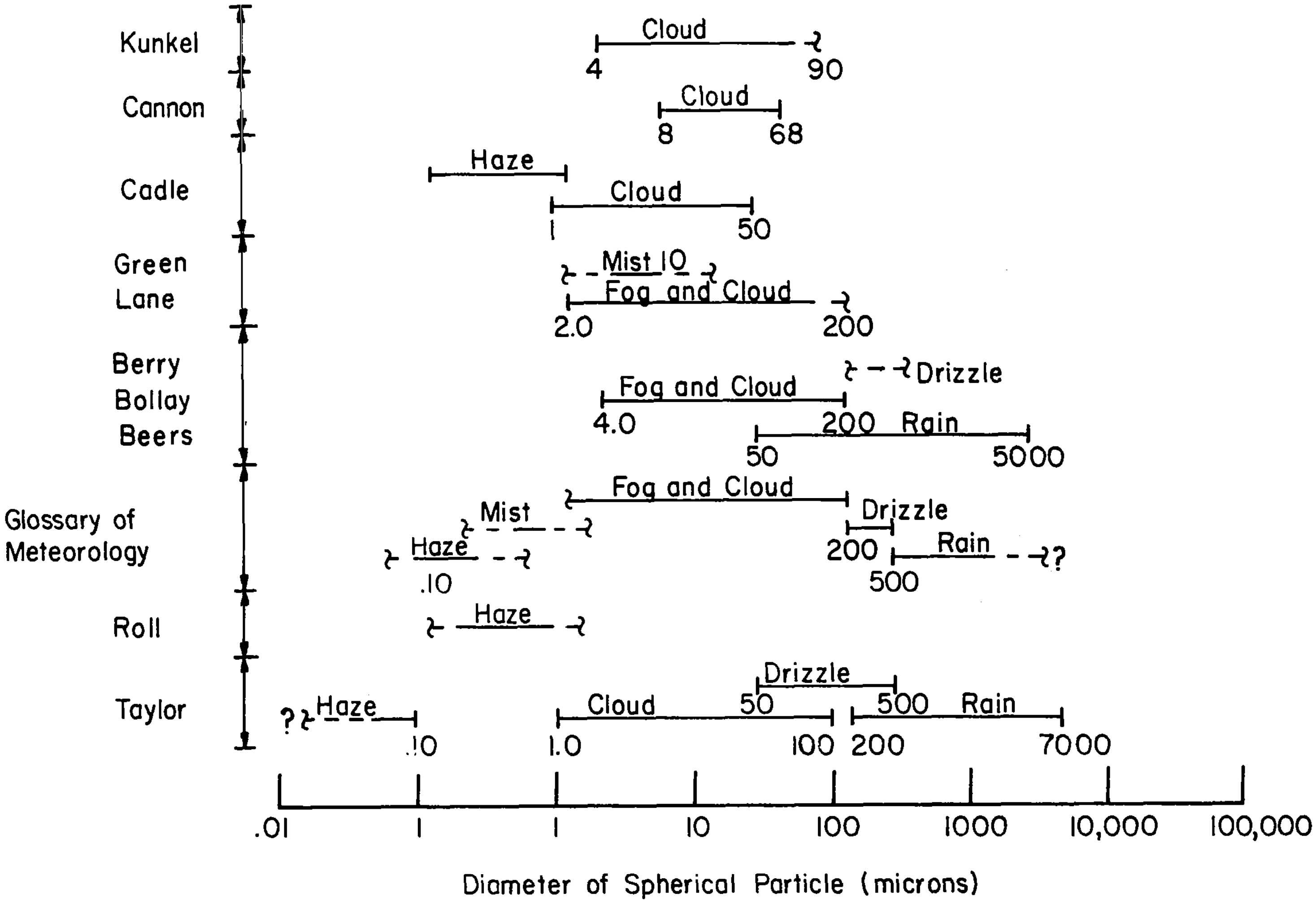


Figure 1: Droplet Size Variations in Rain and Mist

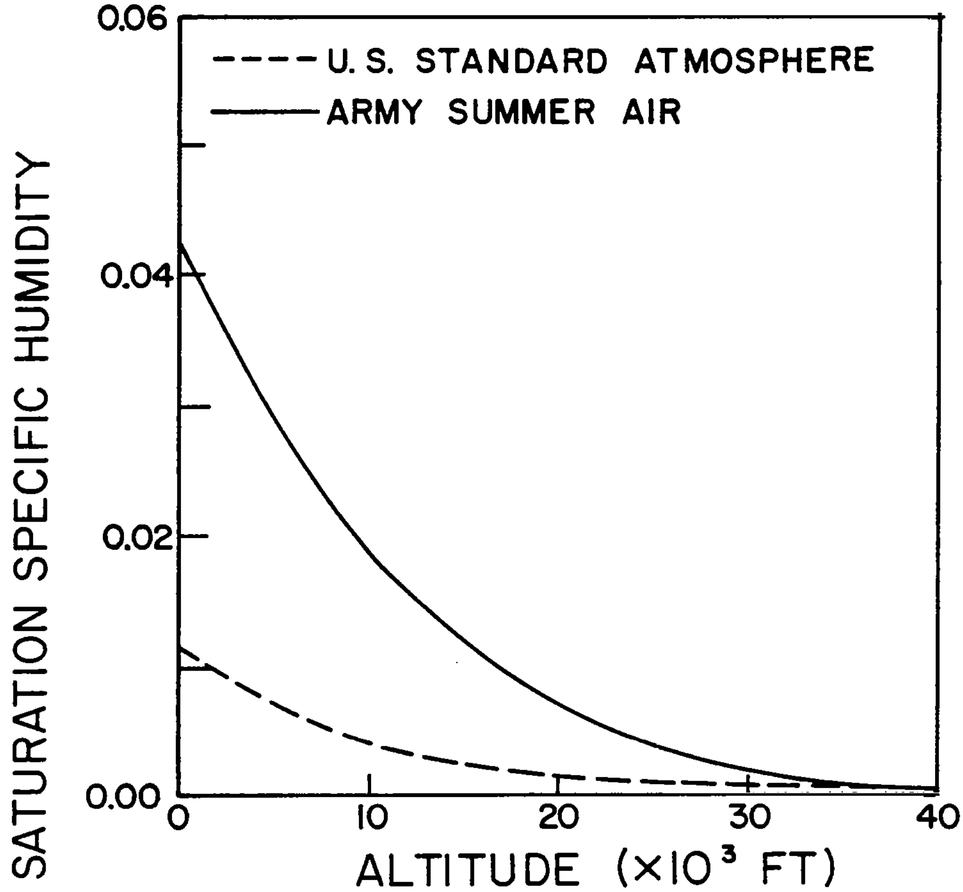


Figure 2: Variation of Saturation Water Vapor Content in Ambient Air as a Function of Altitude

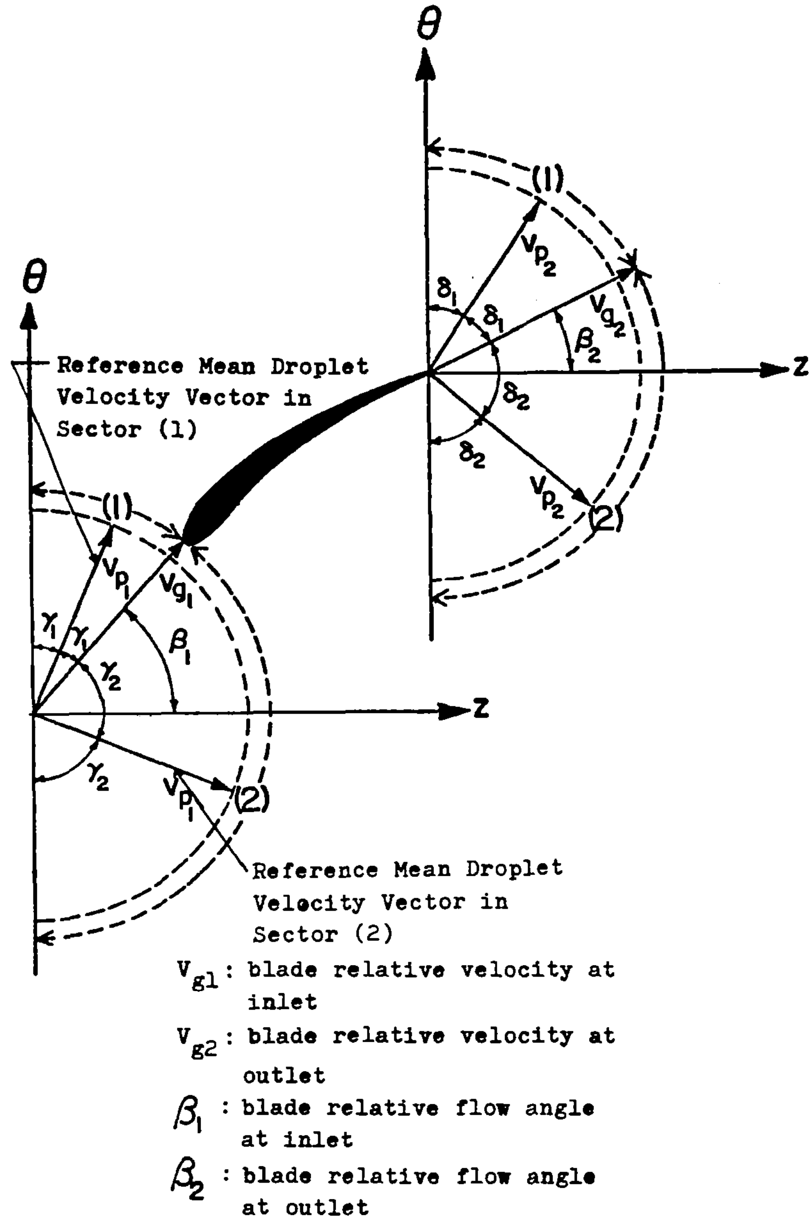


Figure 3: Model for Large Droplet Motion

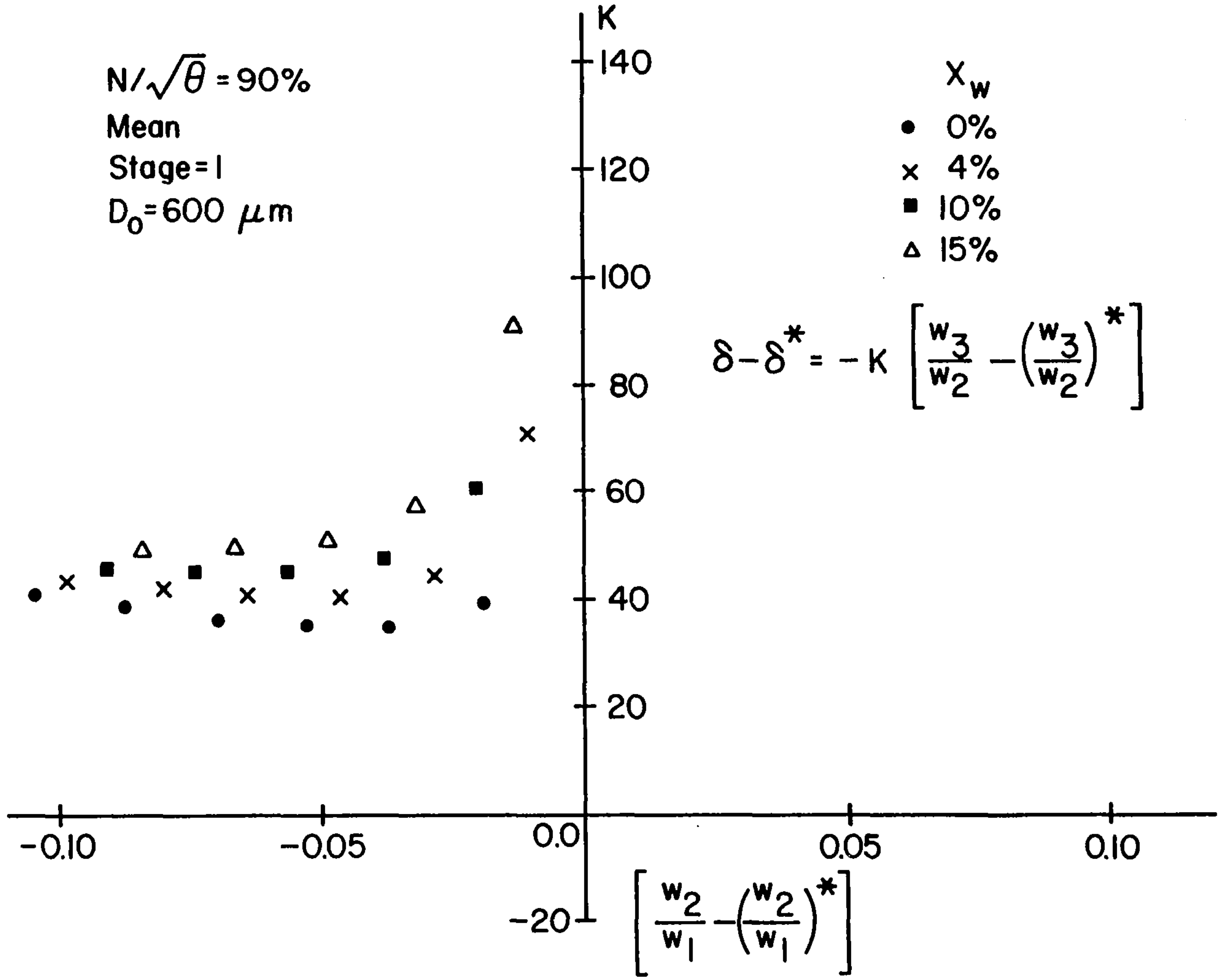


Figure 4(a): Deviation Constant vs Diffusion (Stage = 1)

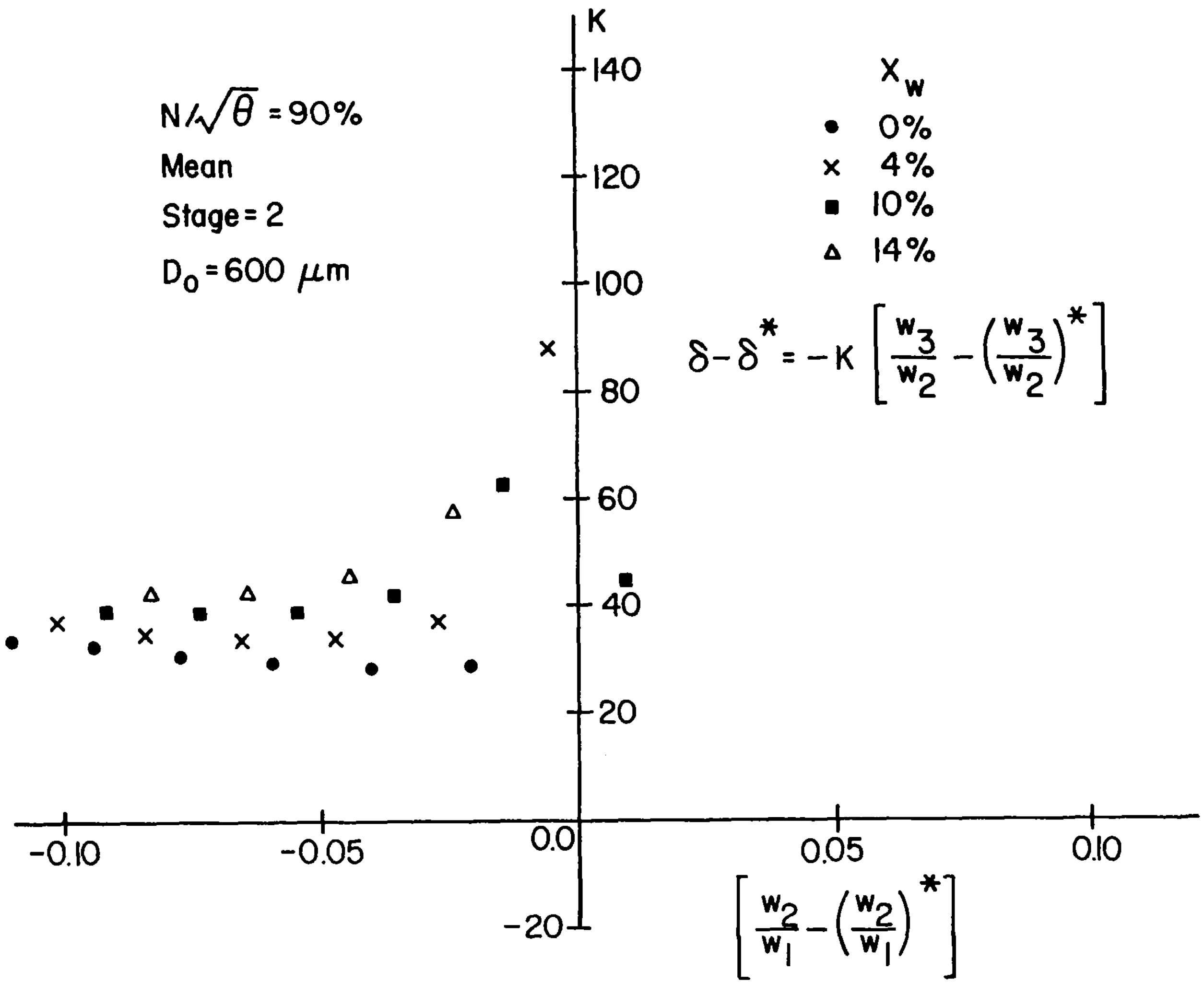


Figure 4(b): Deviation Constant vs Diffusion (Stage = 2)

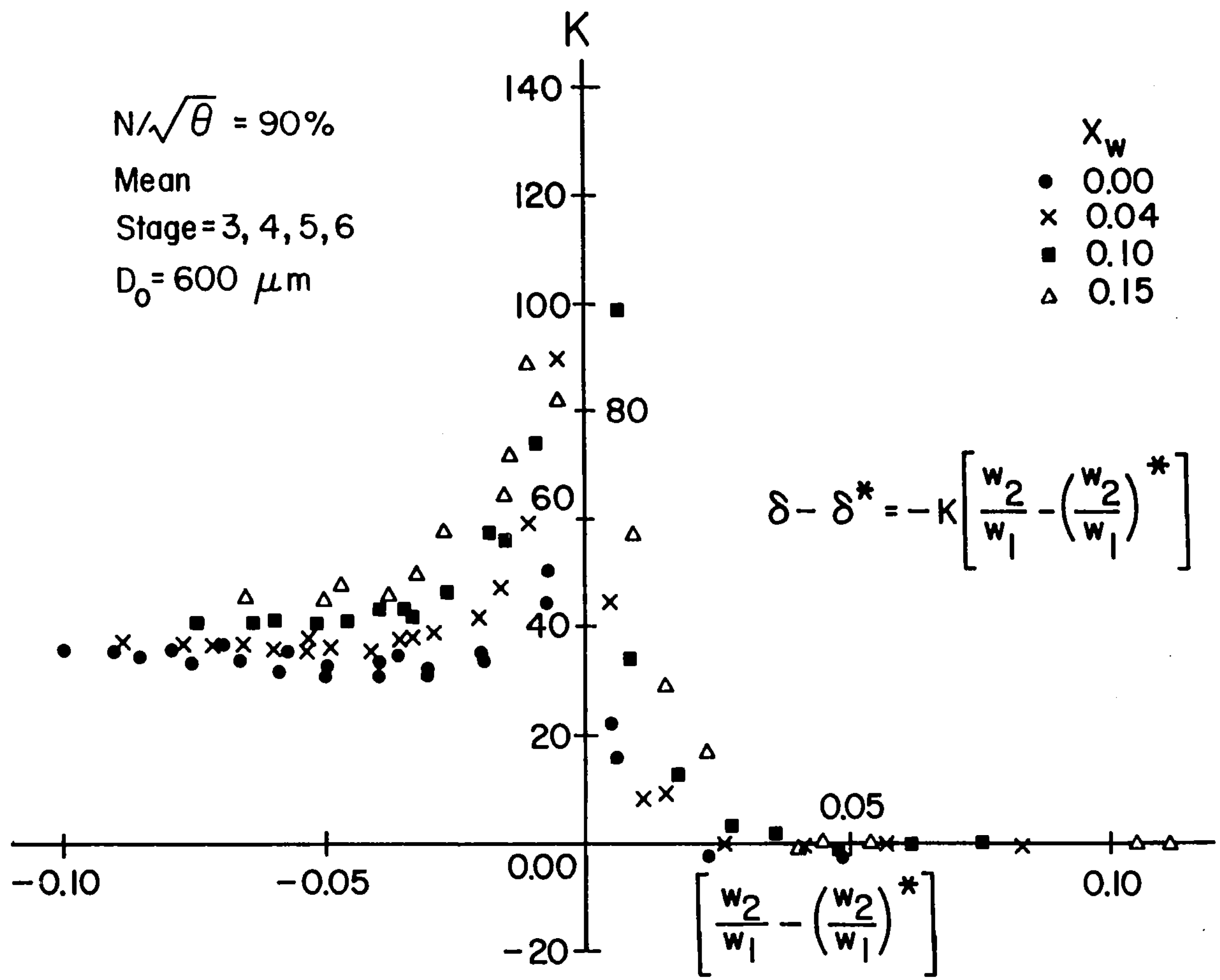


Figure 4(c): Deviation Constant vs Diffusion (Stage = 3-6)

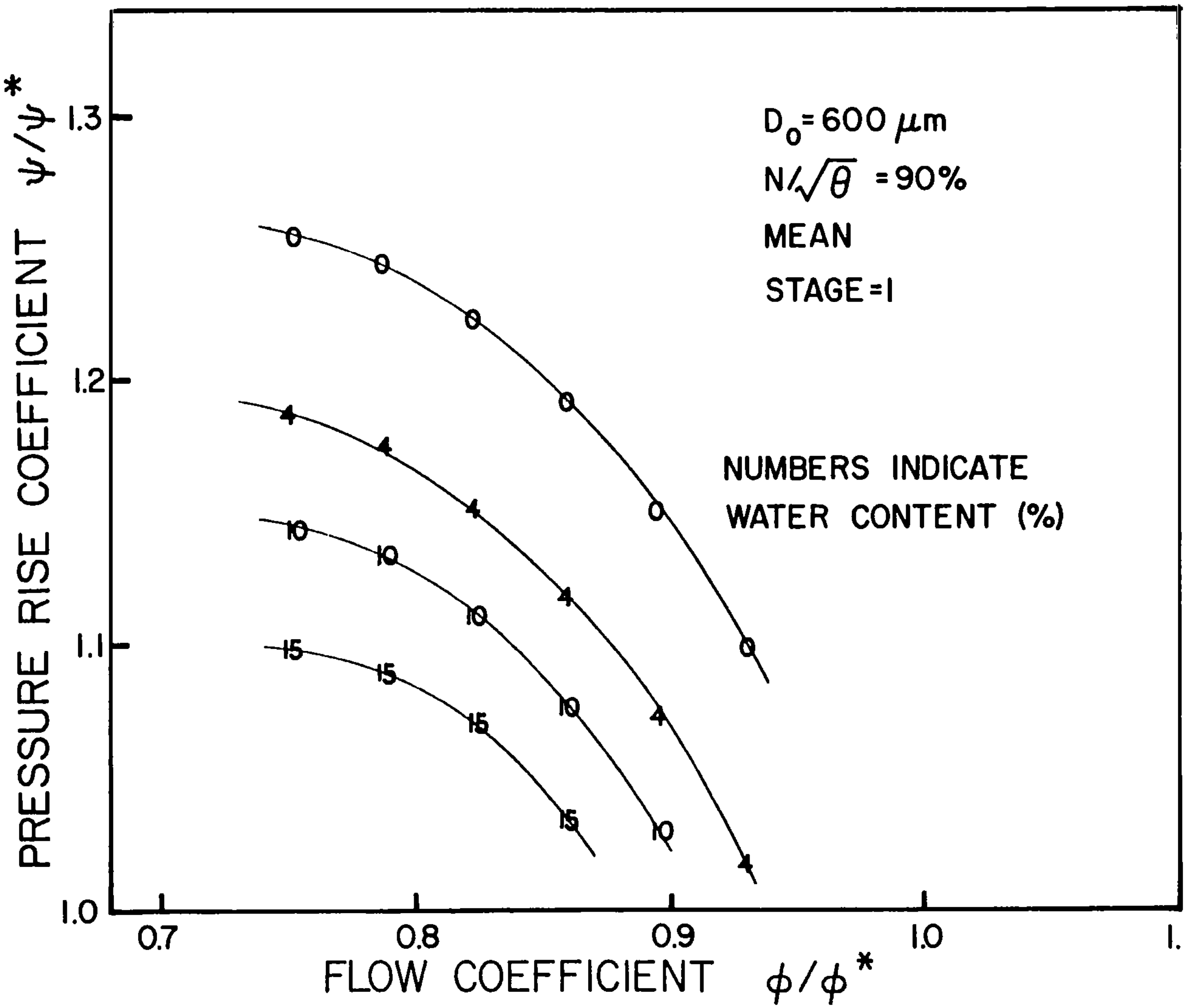


Figure 5(a): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 1)

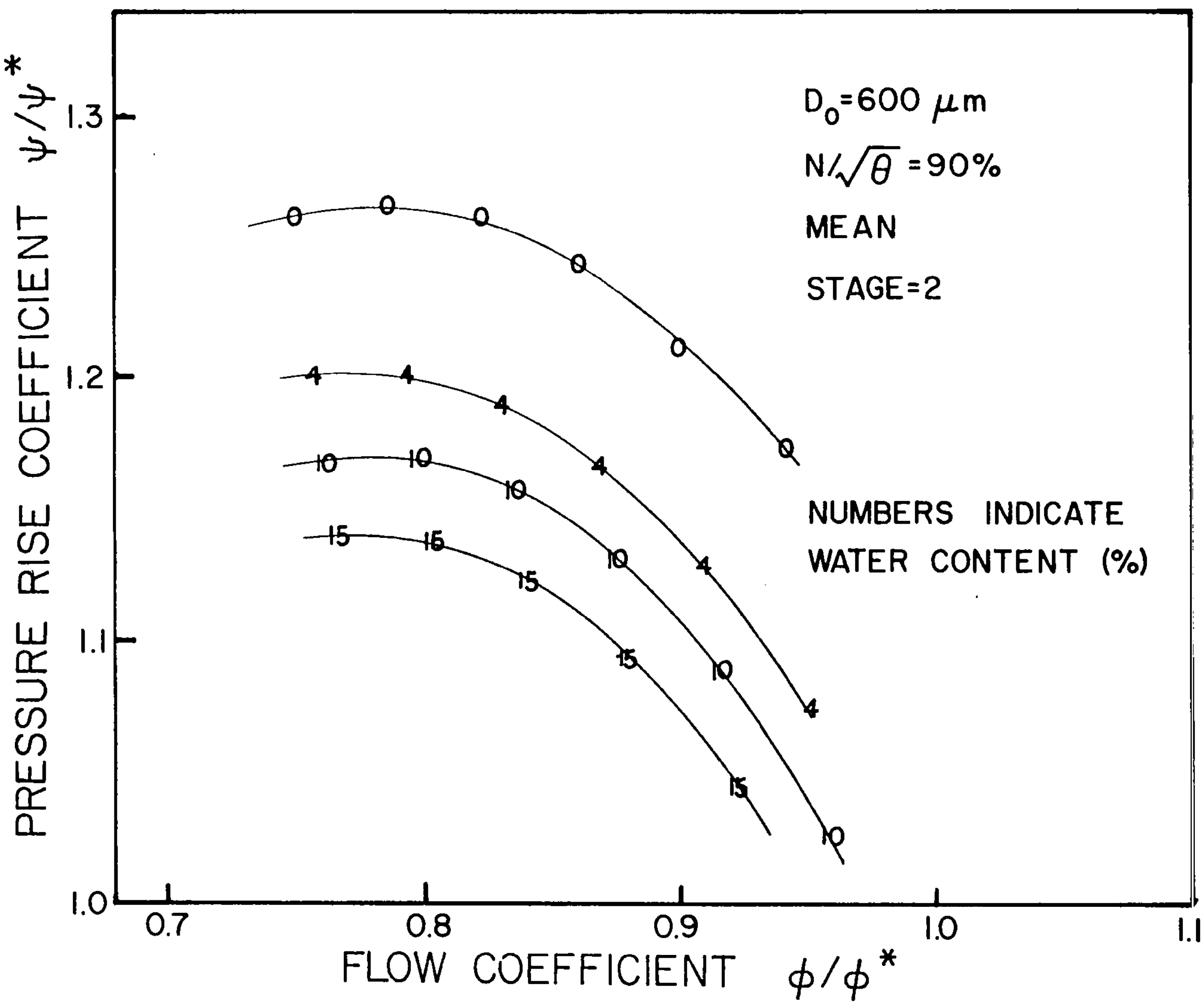


Figure 5(b): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 2)

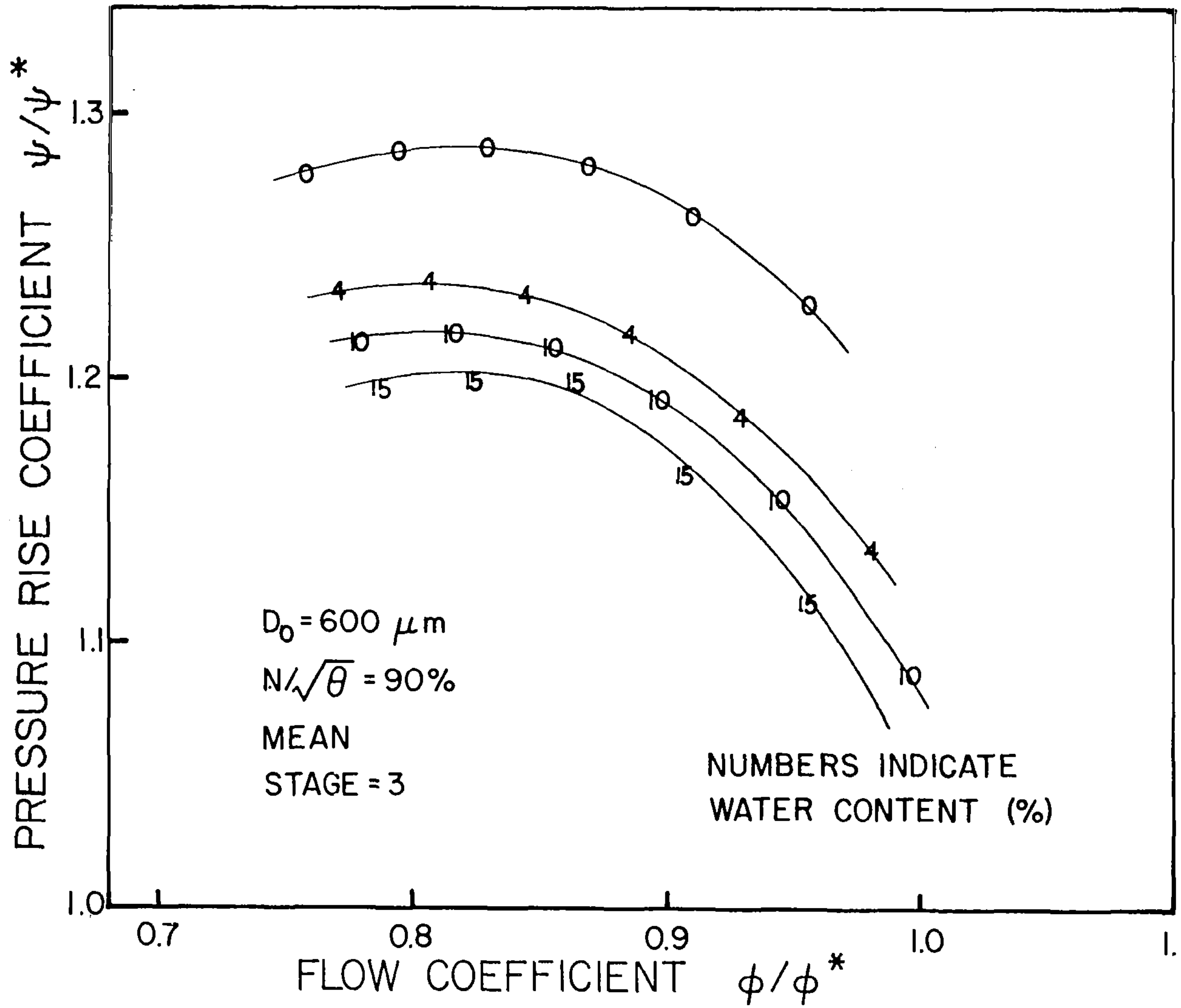


Figure 5(c): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 3)

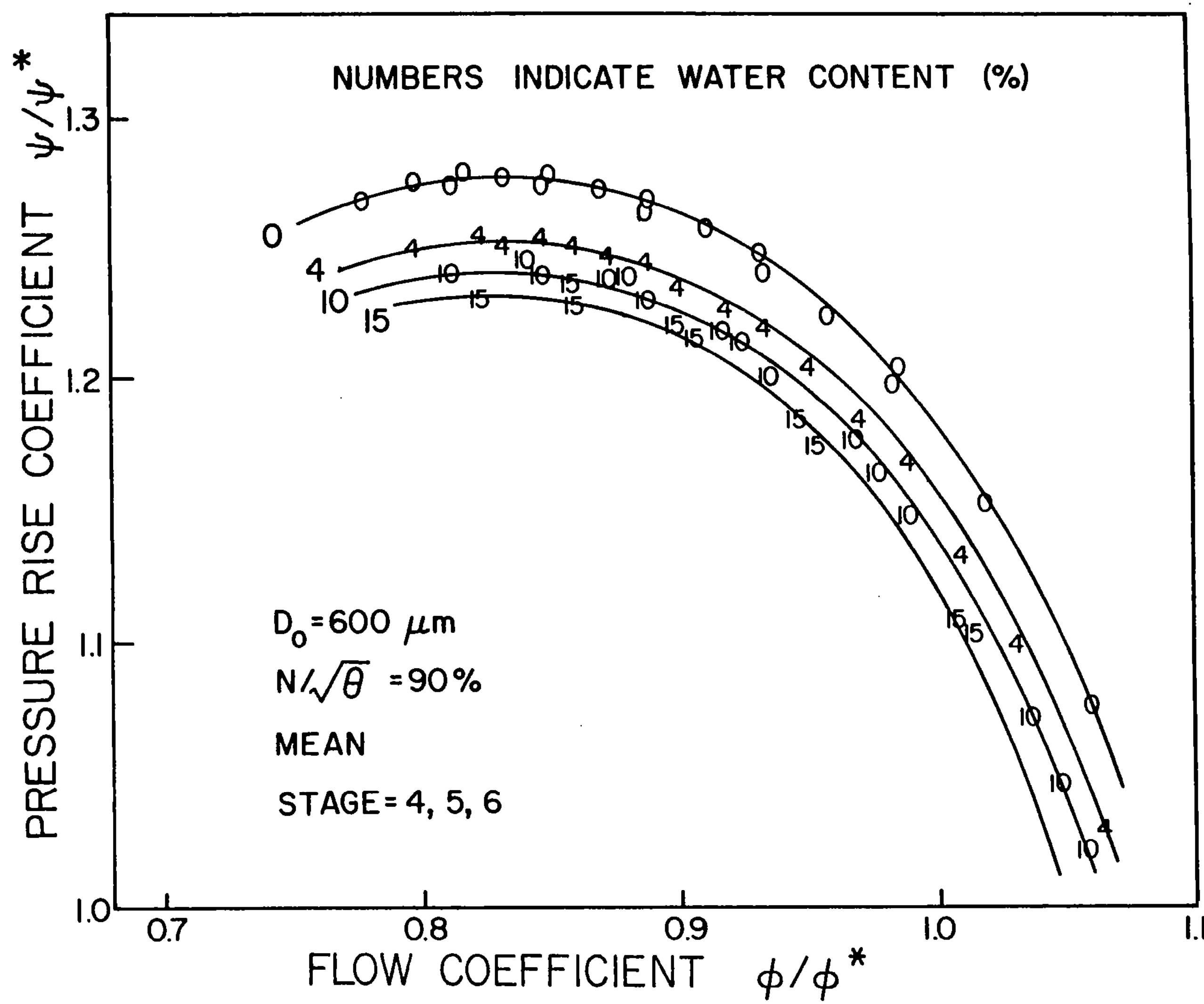


Figure 5(d): Pressure-Rise Coefficient vs Flow Coefficient (Stage = 4-6)

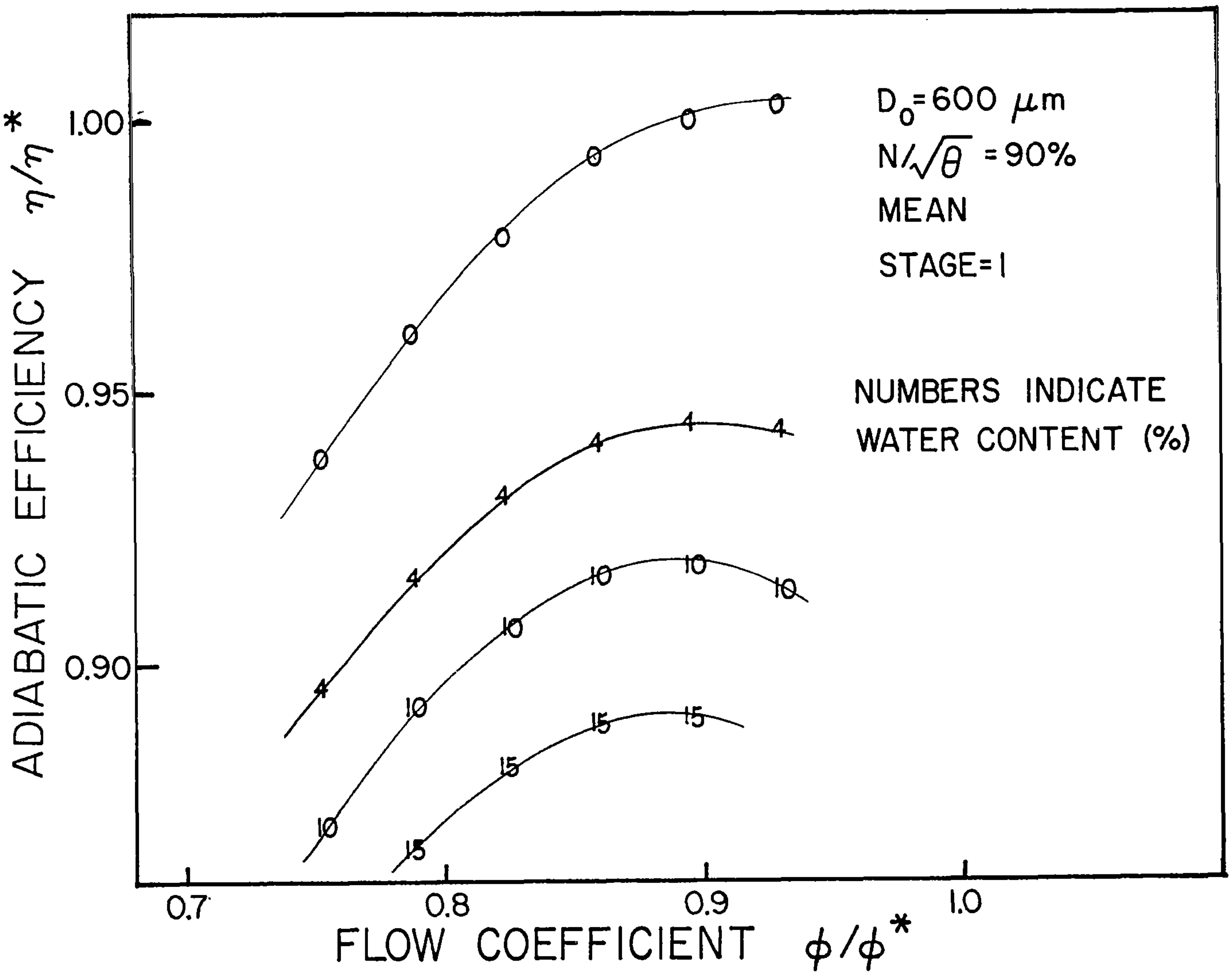


Figure 6(a): Efficiency vs Flow Coefficient (Stage = 1)

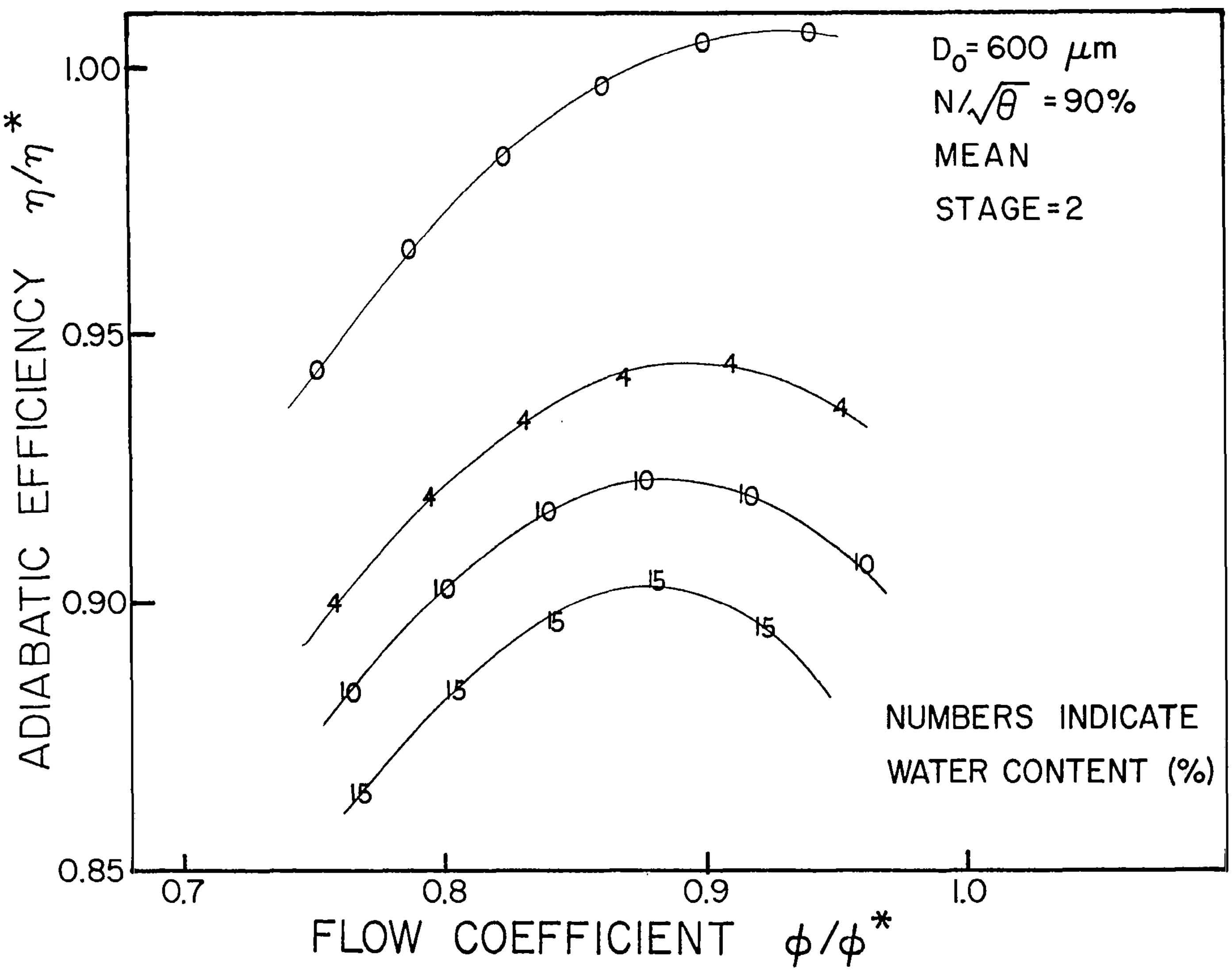


Figure 6(b): Efficiency vs Flow Coefficient (Stage = 2)

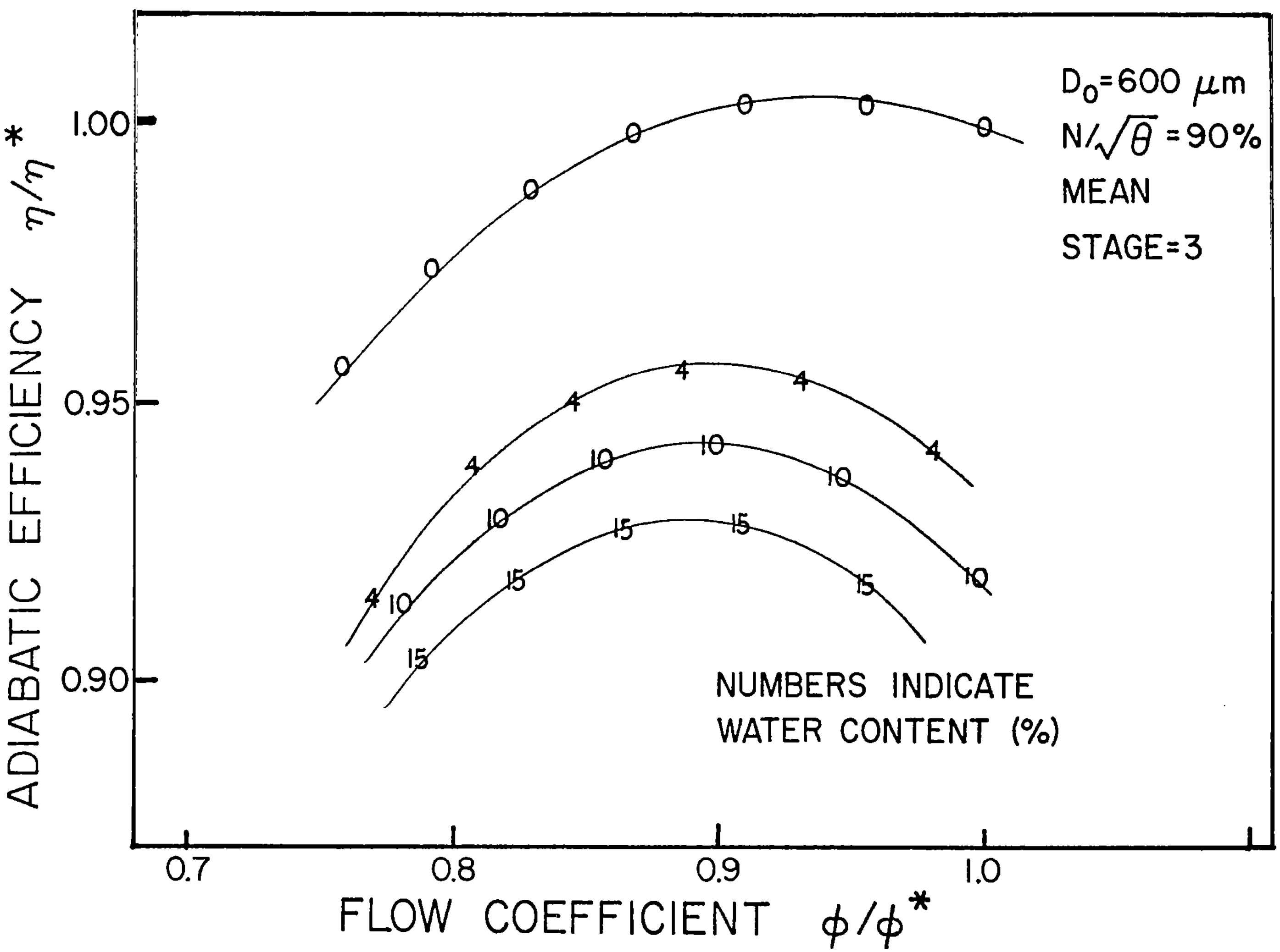


Figure 6(c): Efficiency vs Flow Coefficient (Stage = 3)

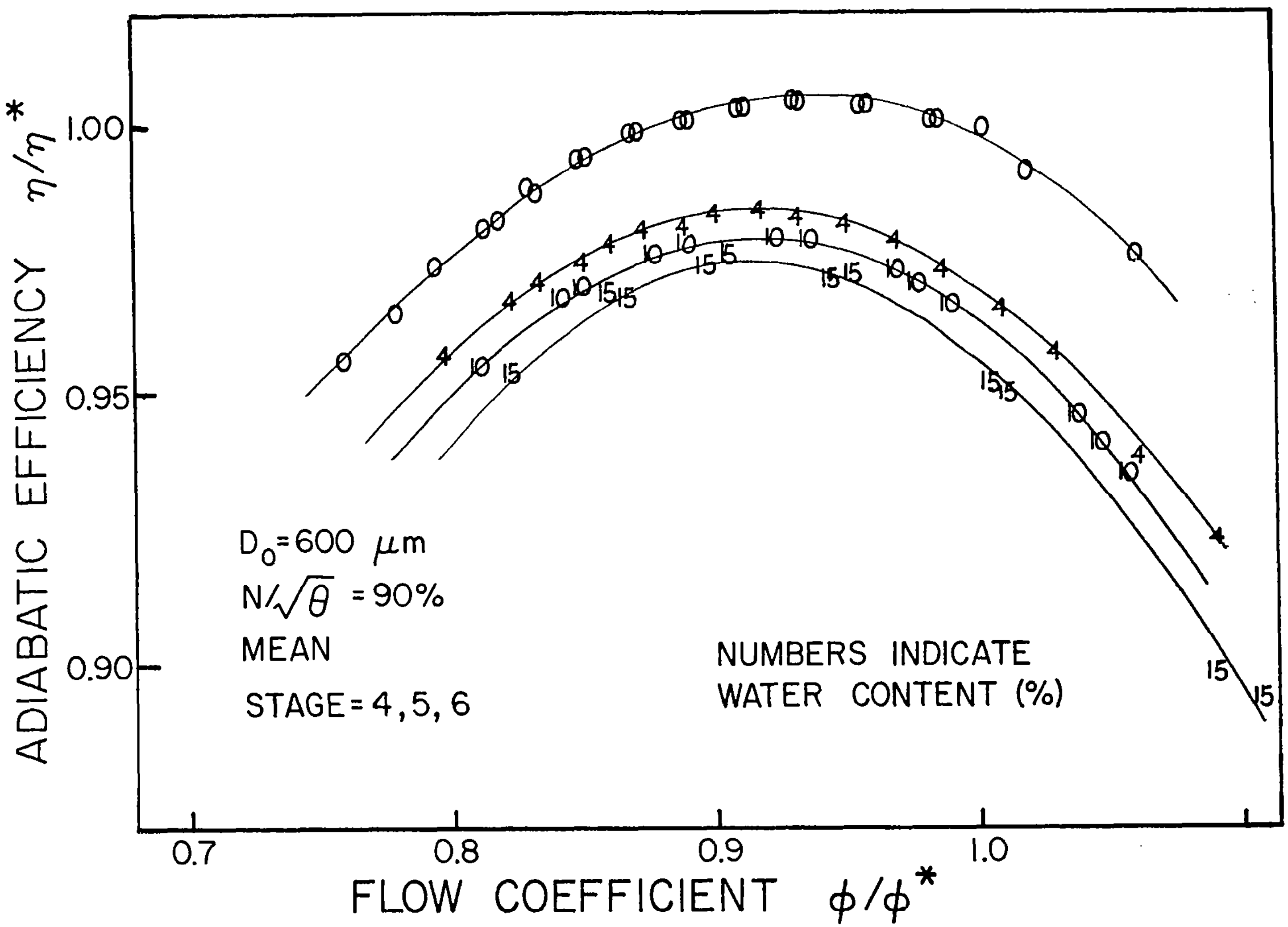


Figure 6(d): Efficiency vs Flow Coefficient (Stage = 4-6)

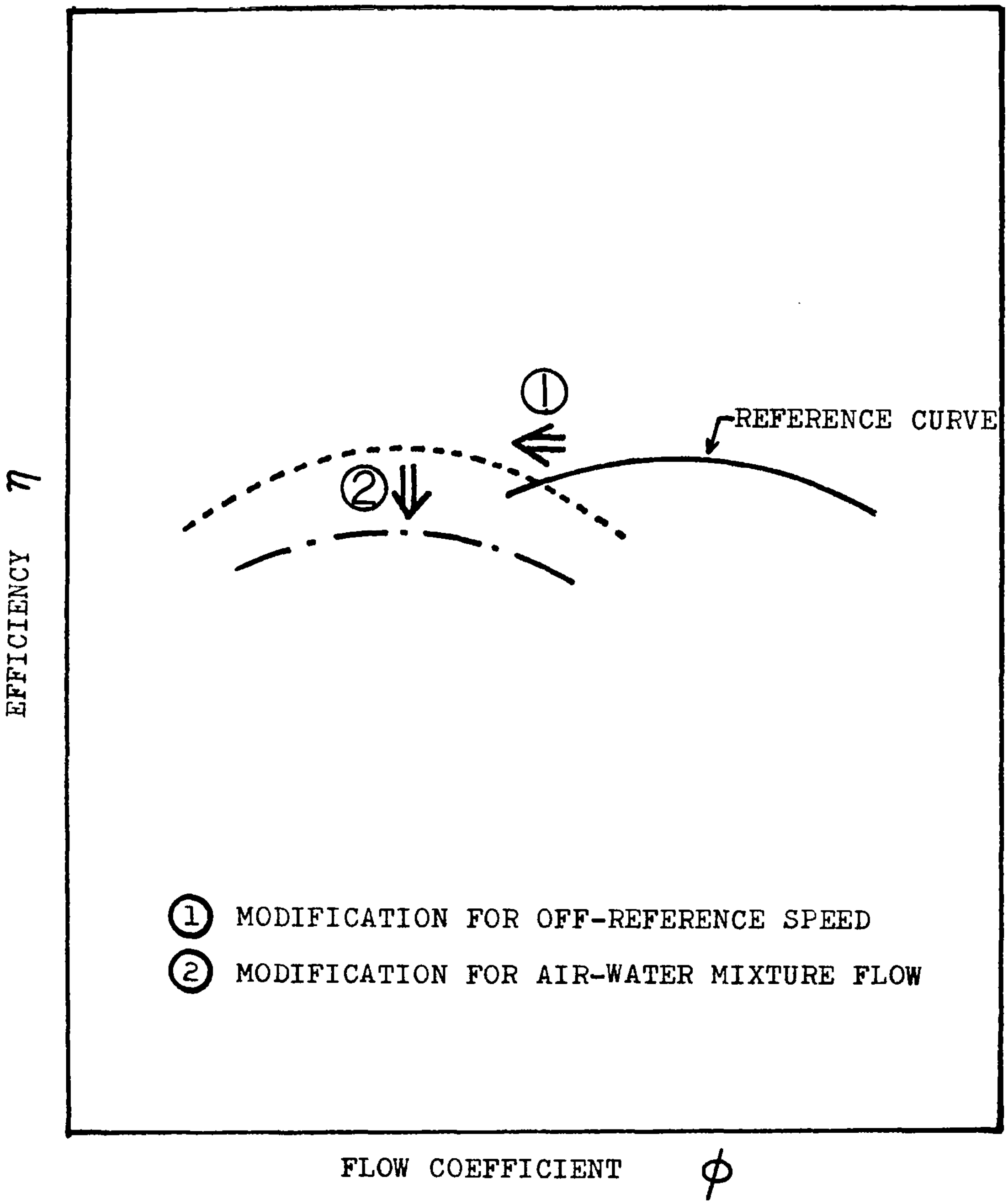


Figure 7: Modification of Reference Efficiency Curve

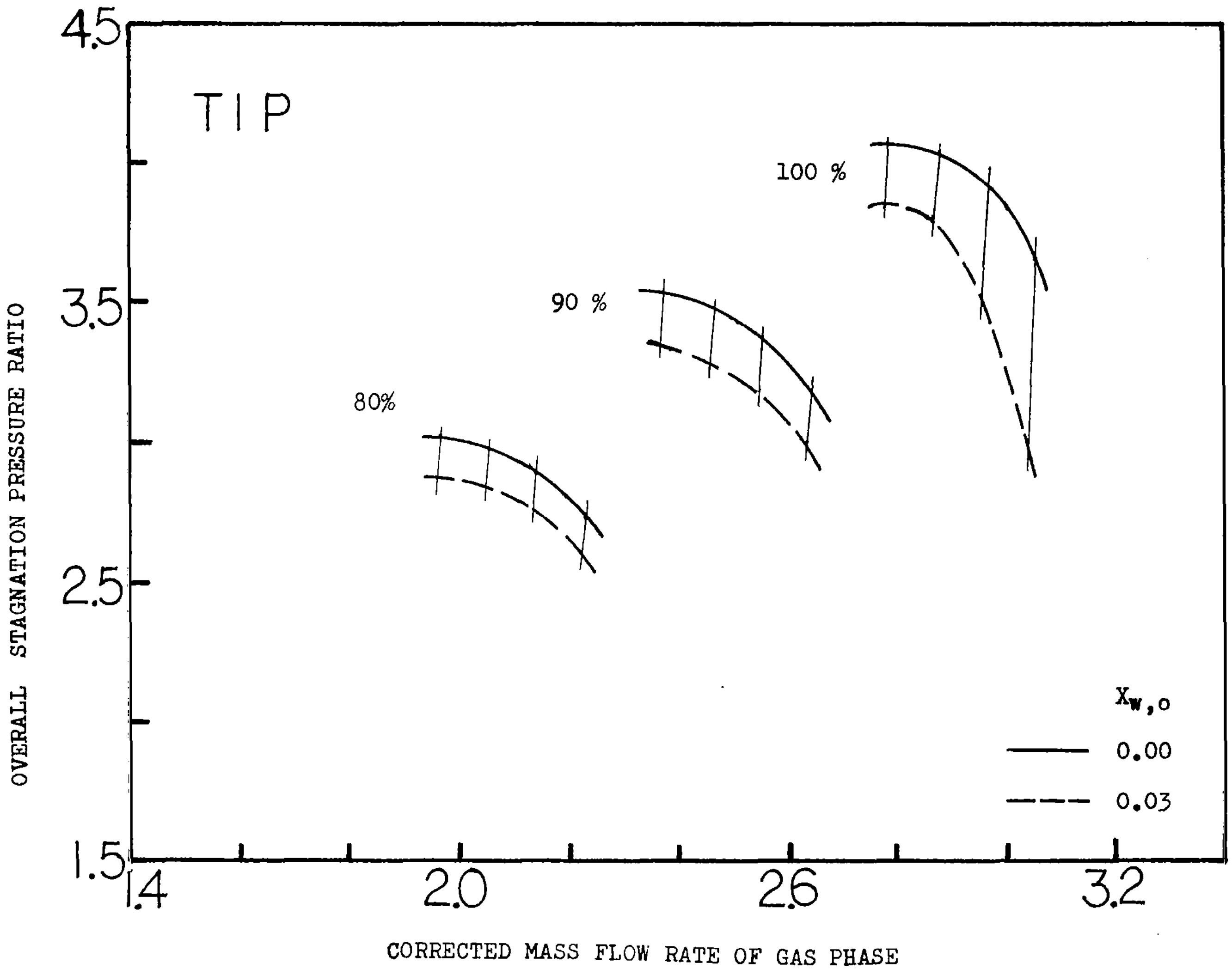


Figure 8(a): Predicted Overall Stagnation Pressure Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Tip Section

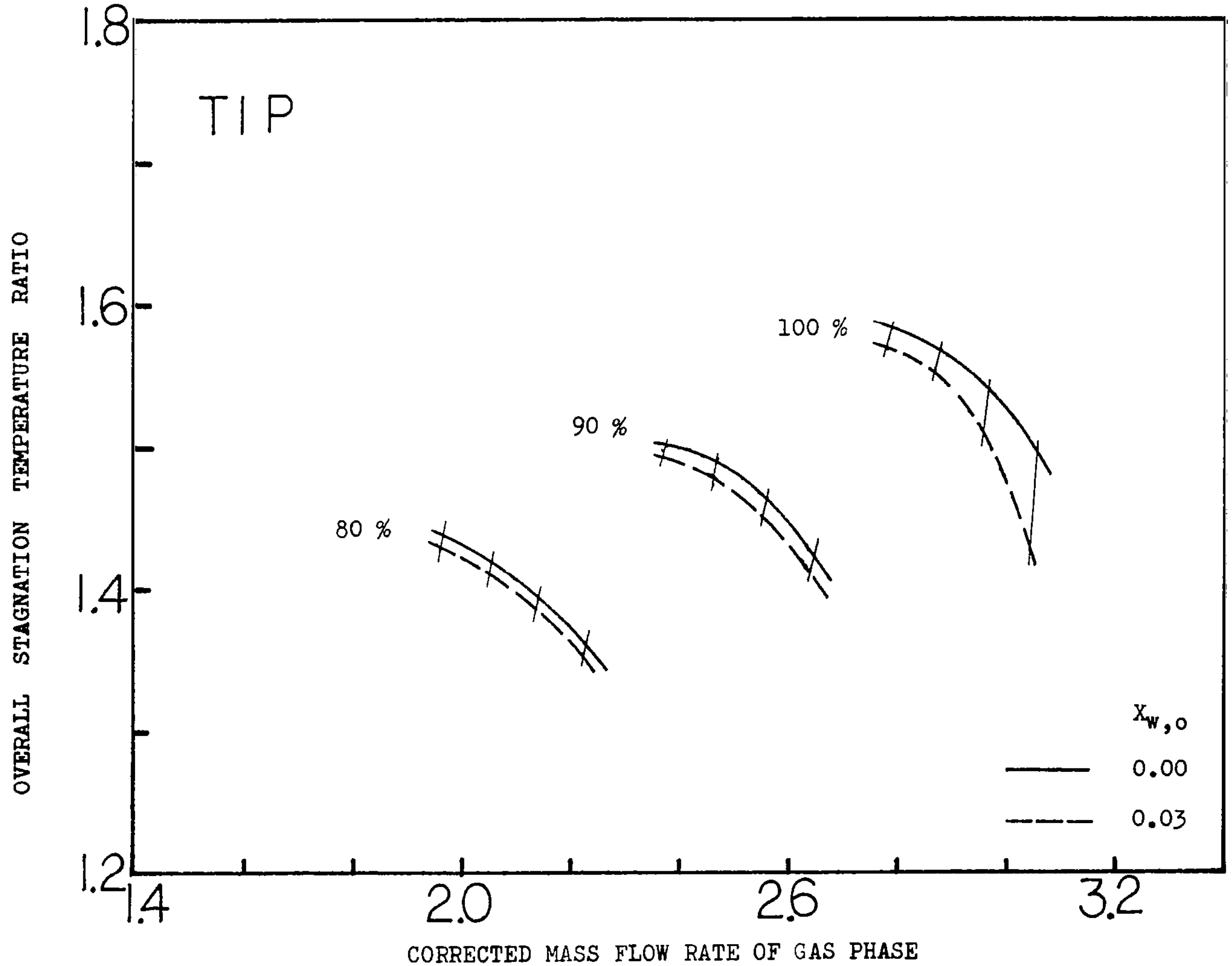


Figure 8(b): Predicted Overall Stagnation Temperature Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Tip Section

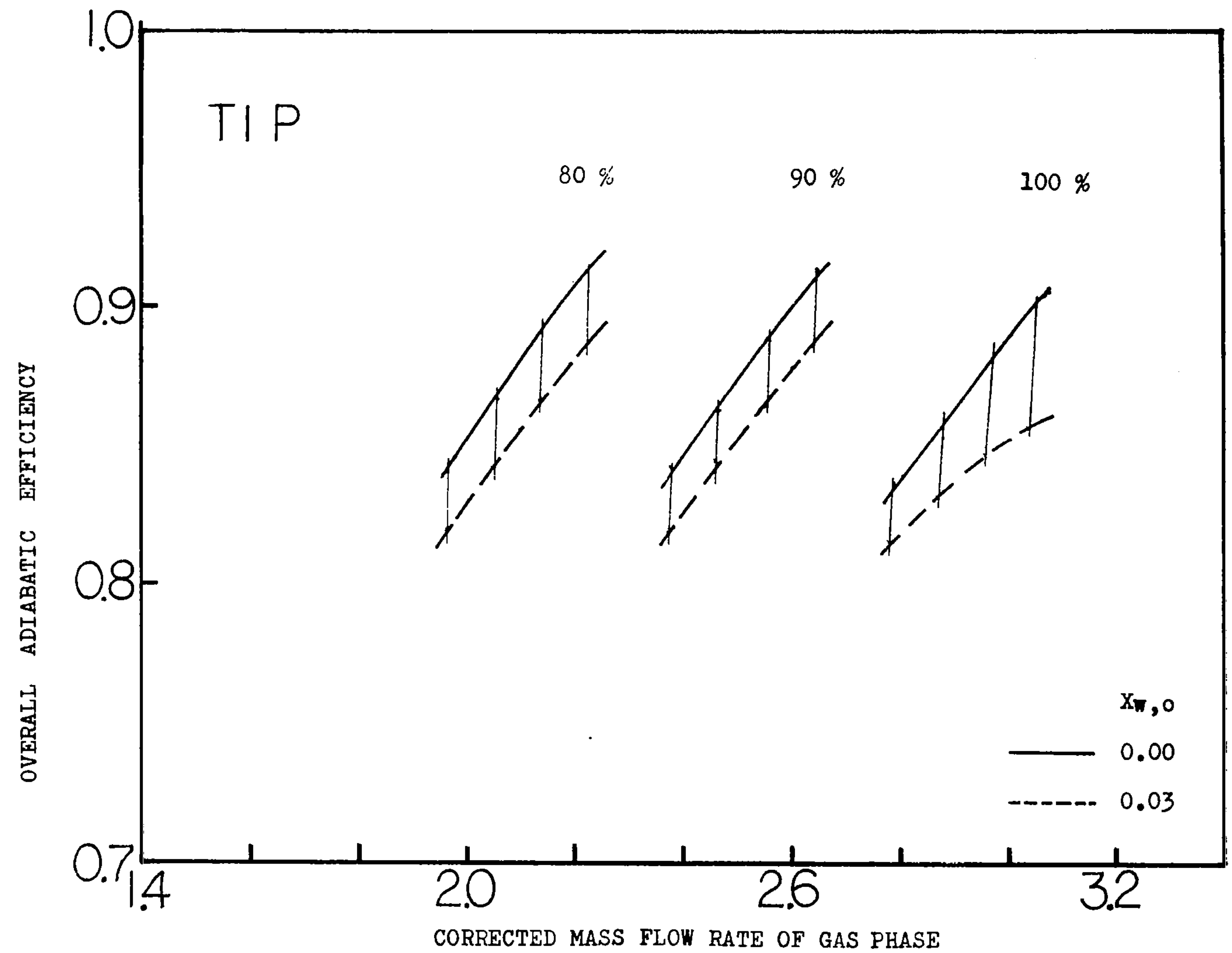


Figure 8(c): Predicted Overall Adiabatic Efficiency as a Function of Gas Phase Corrected Mass Flow at Tip Section

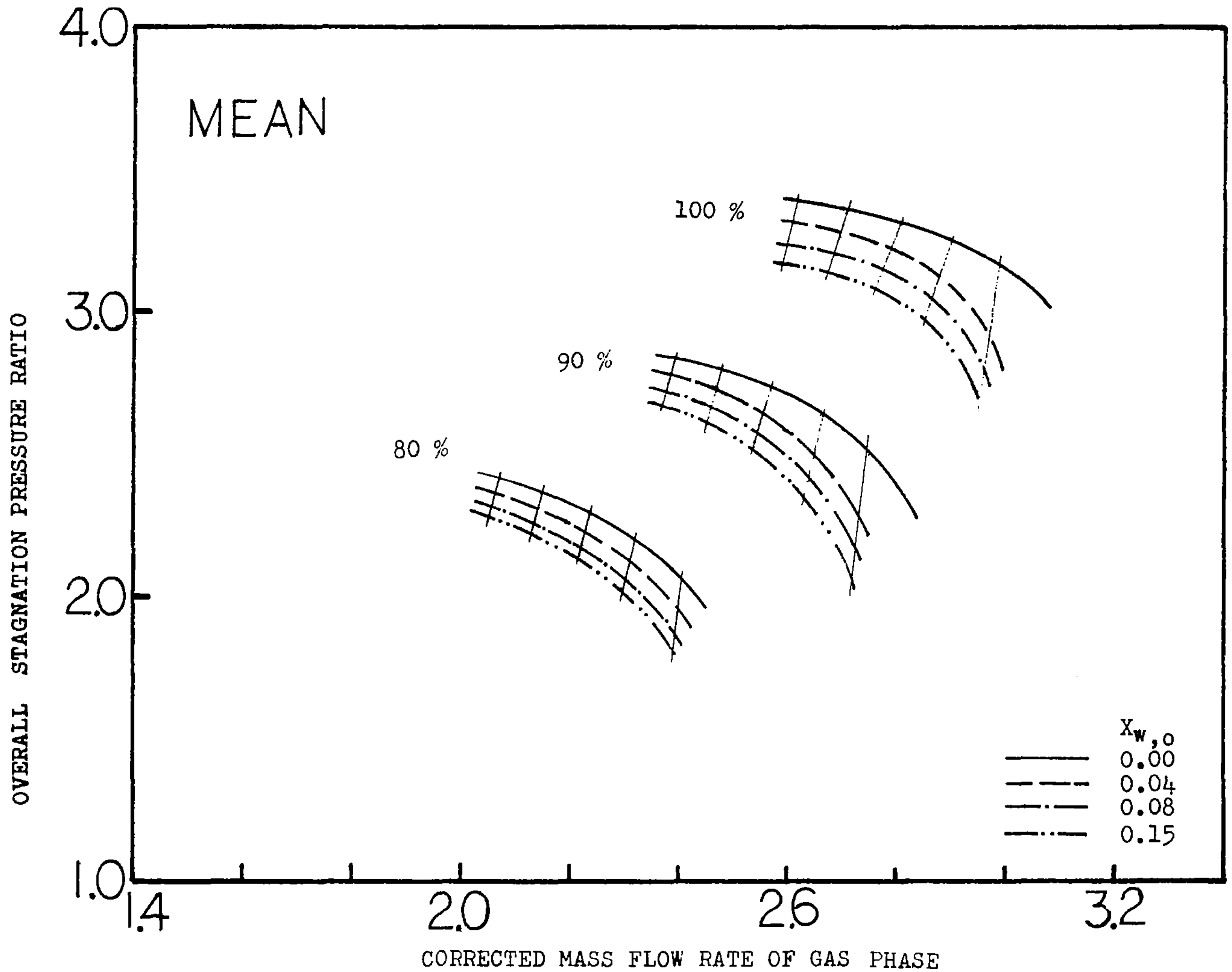


Figure 9(a): Predicted Overall Stagnation Pressure Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Mean Section

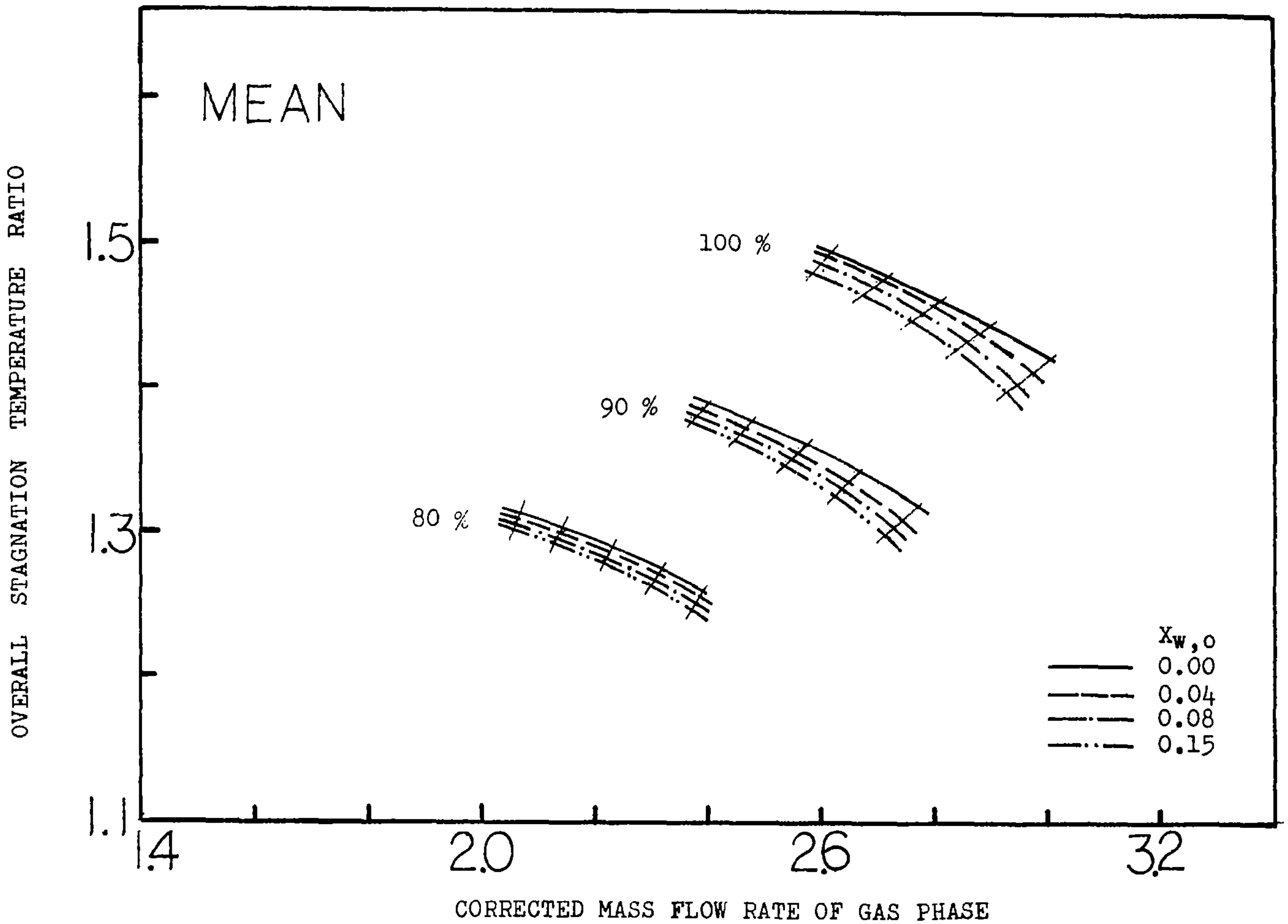


Figure 9(b): Predicted Overall Stagnation Temperature Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Mean Section

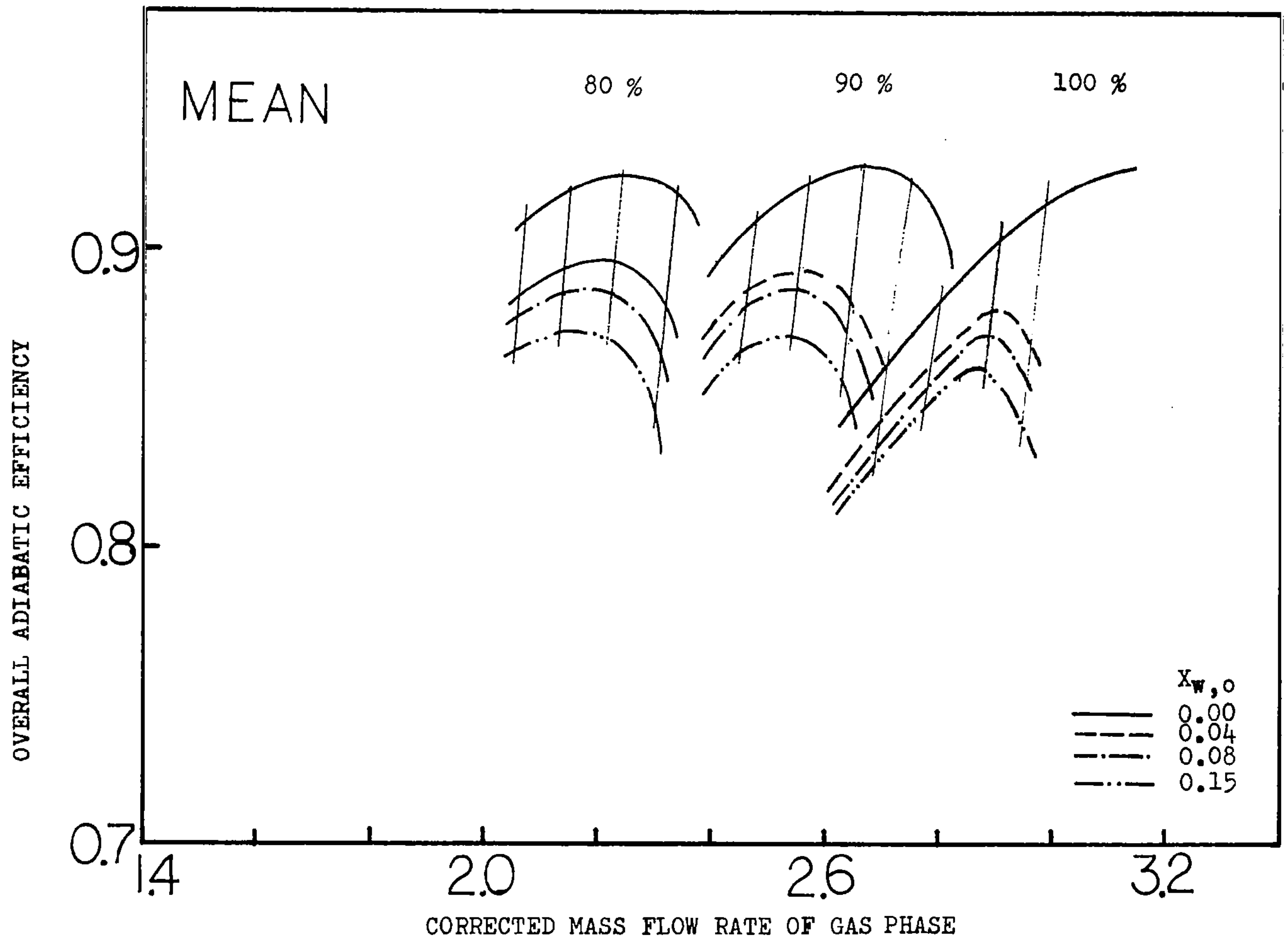


Figure 9(c): Predicted Overall Adiabatic Efficiency as a Function of Gas Phase Corrected Mass Flow Rate at Mean Section

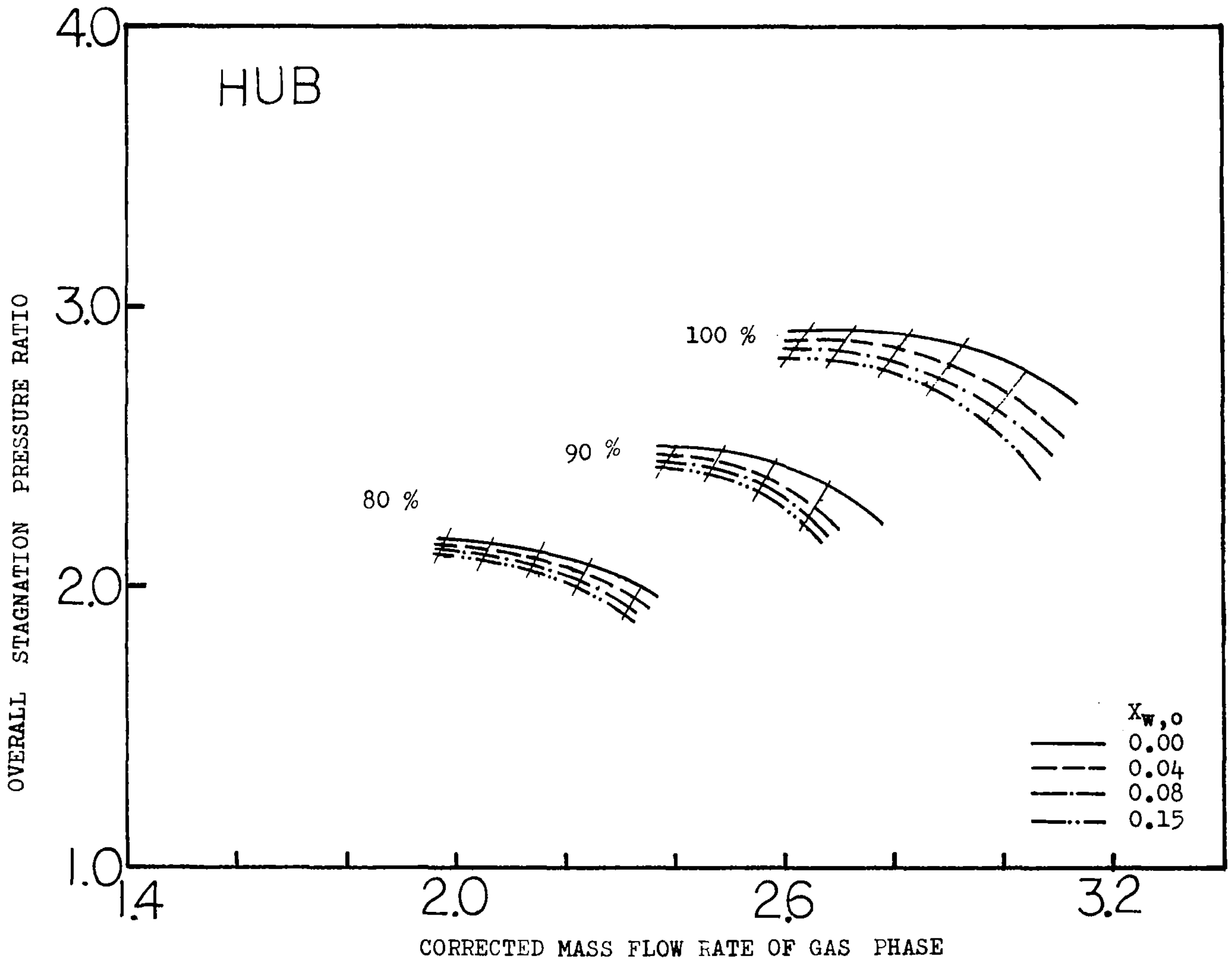


Figure 10(a): Predicted Overall Stagnation Pressure Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Hub Section

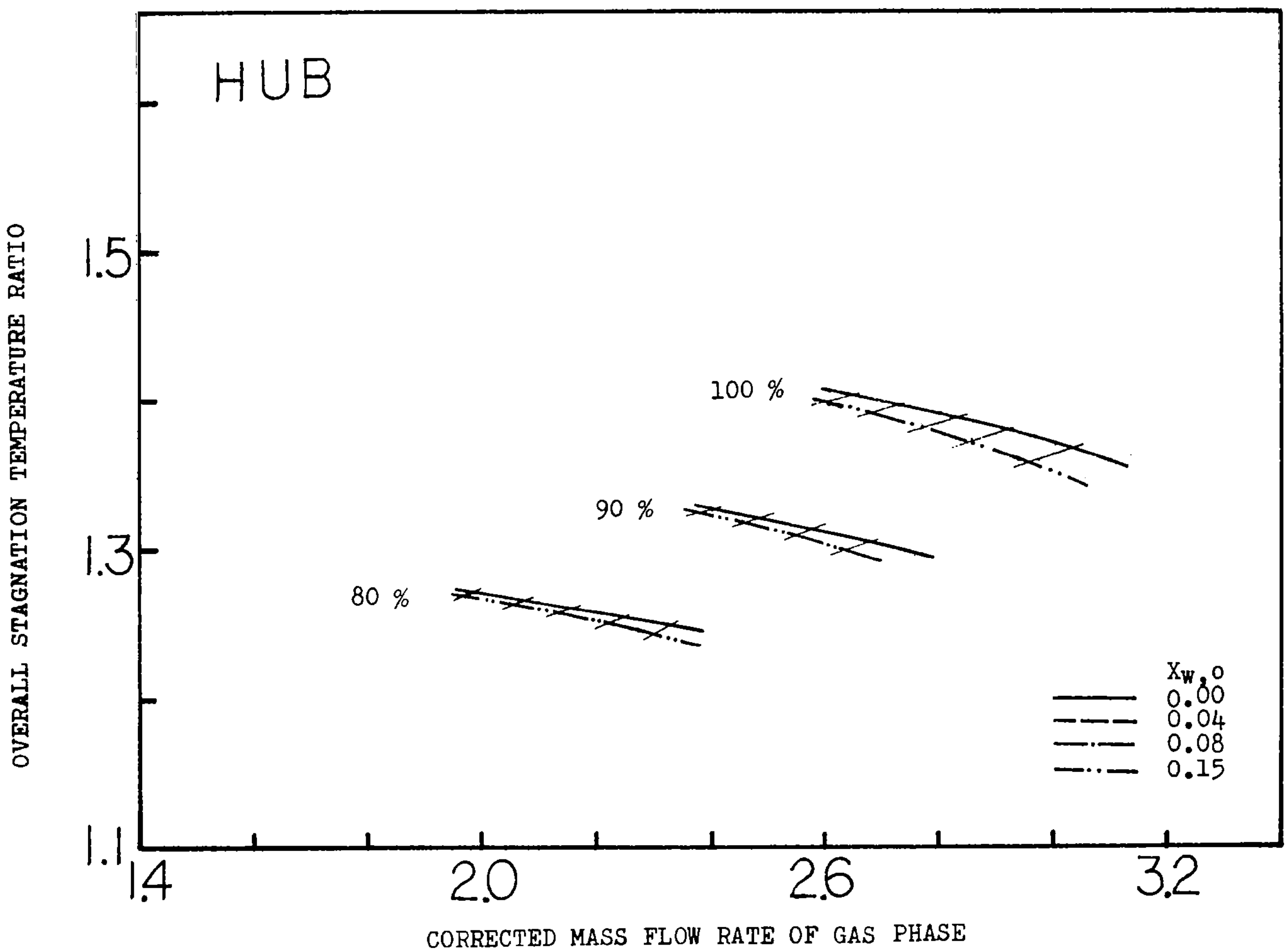


Figure 10(b): Predicted Overall Stagnation Temperature Ratio as a Function of Gas Phase Corrected Mass Flow Rate at Hub Section

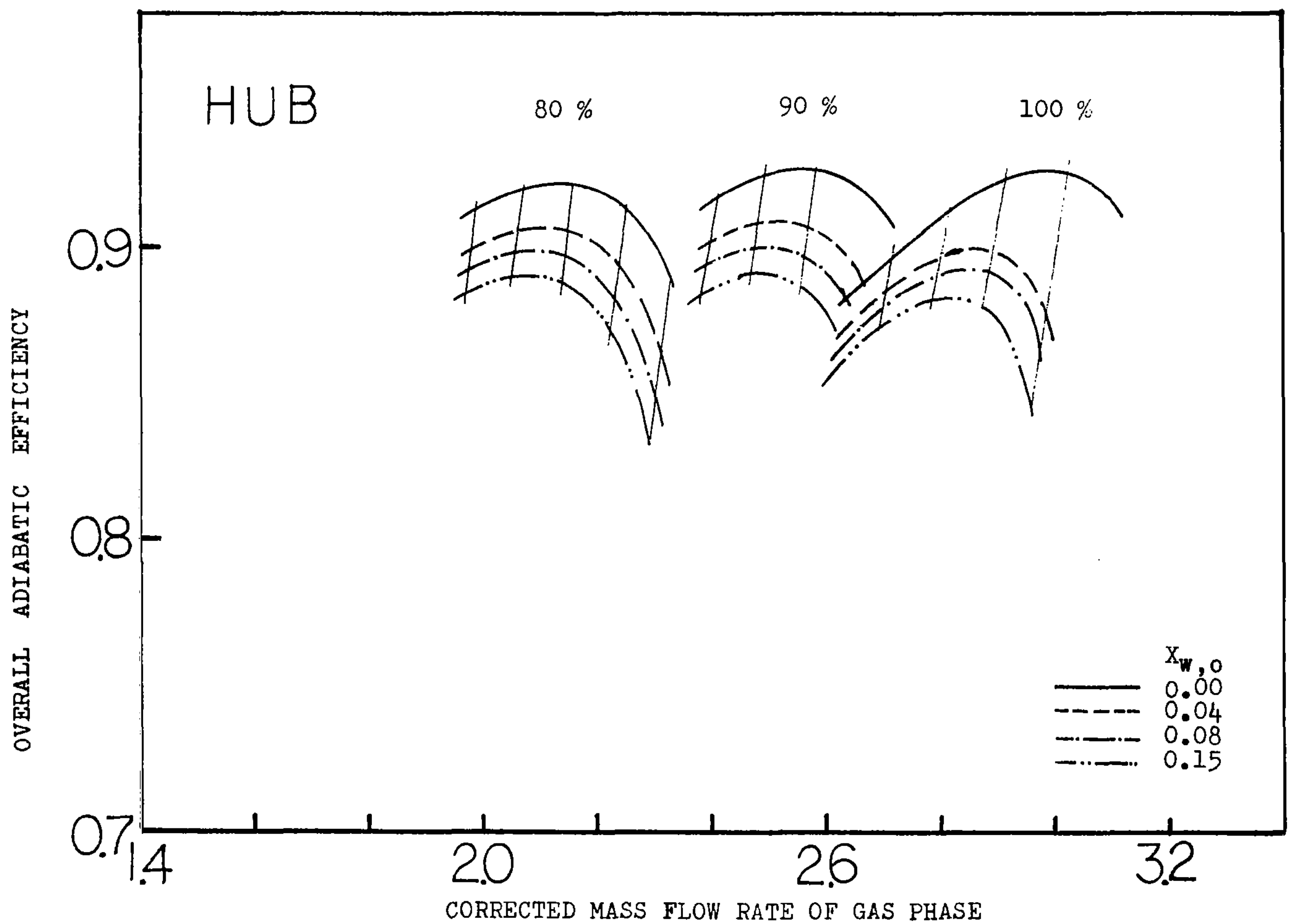


Figure 10(c): Predicted Overall Adiabatic Efficiency as a Function of Gas Phase Corrected Mass Flow Rate at Hub Section

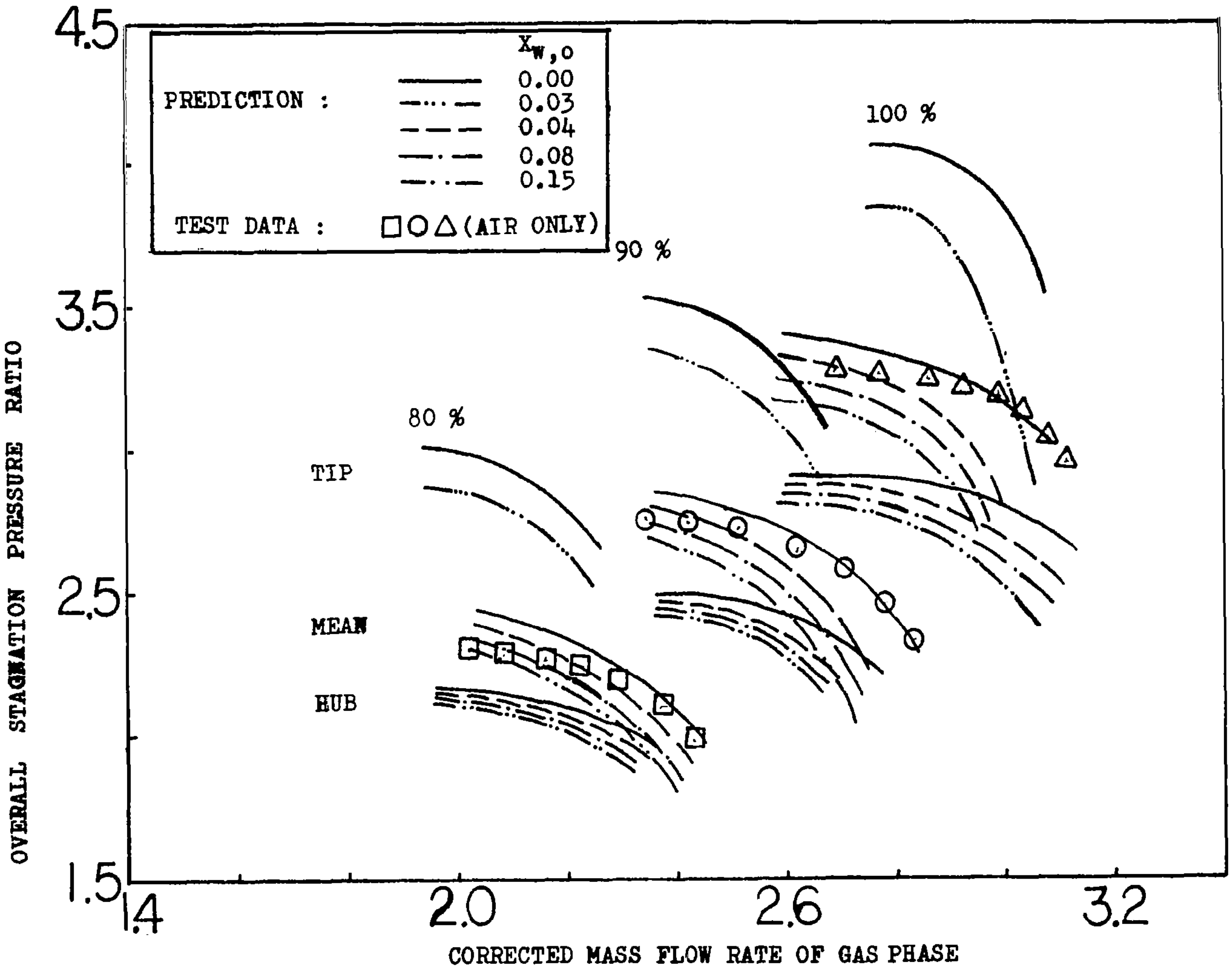


Figure 11(a): Overall Stagnation Pressure Ratio vs Gas Phase Corrected Mass Flow Rate ($N/\sqrt{\theta}$ = 80, 90, 100%, and Test Data)

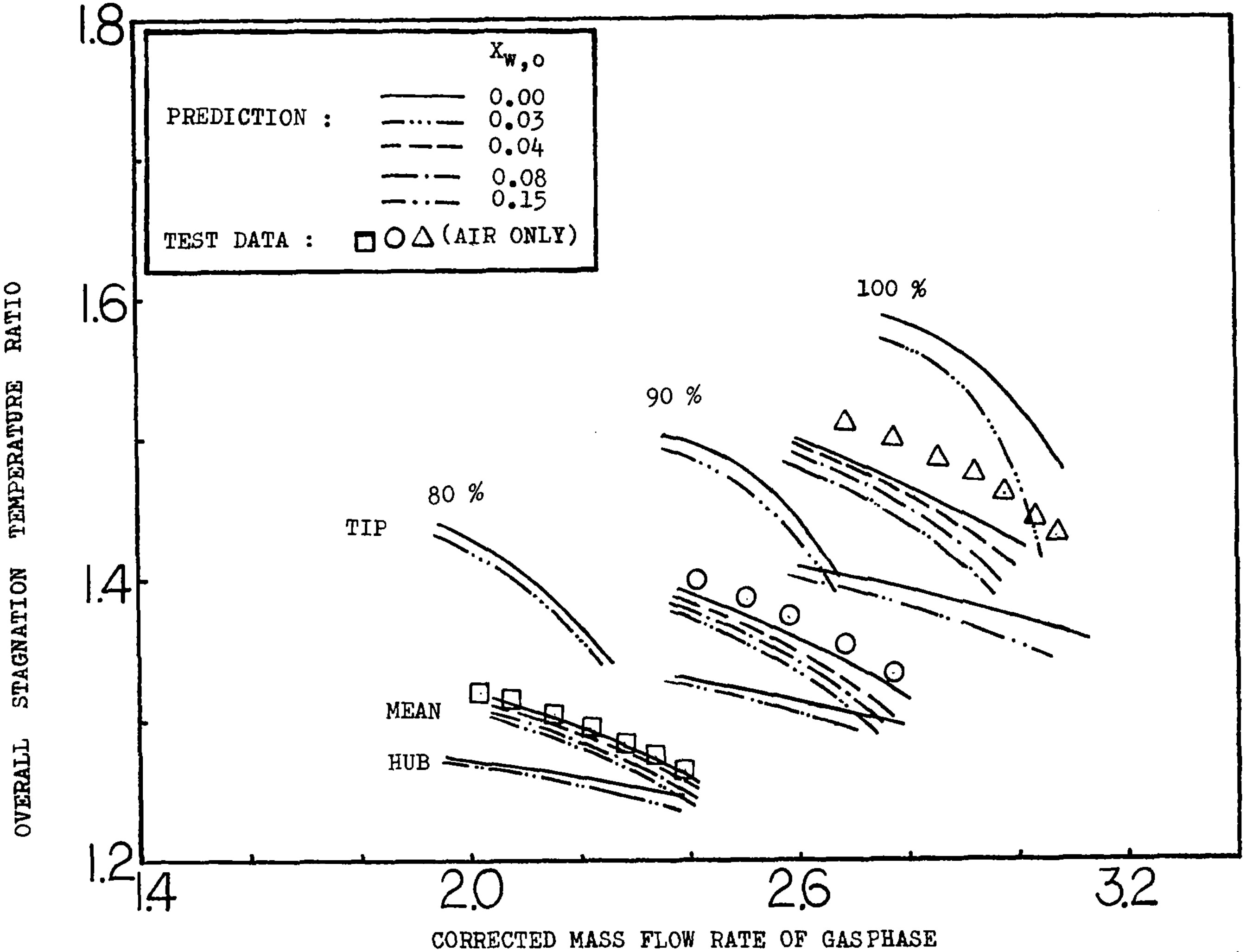


Figure 11(b): Overall Stagnation Temperature Ratio vs Gas Phase Corrected Mass Flow Rate ($N/\sqrt{\theta}$ = 80, 90, 100% and Test Data )

## REFERENCES


1. (a) "Concorde Complete Flooded Runway Tests," Aviation Week and Space Technology, p. 22, October 4, 1971.
   (b) "Board Assays Crash of DC-9 in Storm," Ibid, pp. 63-67, July 24, 1978.
   (c) "Storm Traced in Southern DC-9 Crash," Ibid, pp. 59-61, July 31, 1978.
   (d) "Damage Assessed in Southern Crash," Ibid, pp. 59-63, August 7, 1978.
   (e) "Thrust Loss Cited in Southern Accident," Ibid, pp. 55-58, August 21, 1978.
   (f) "Board Urges Improved Thunderstorm Reporting," Ibid, pp. 63-64, August 28, 1978.
   (g) "NTSB Cites Weather Data in Accident," Ibid, pp. 66-70, July 27, 1981.

2. Willenborg, J.A., et al., "F-111 Engine Water Ingestion Review," F-111 System Program Office, Wright-Patterson Air Force Base, Dayton, Ohio, October 31-November 10, 1972.

3. Steinke, R., "STGSTK - A Computer Code for Predicting Multistage Axial-Flow Compressor Performance Using a Meanline Stage-Stacking Method," NASA TP-2020, April 1982.

4. Tsuchiya, T. and Murthy, S.N.B., "Water Ingestion into Axial Flow Compressors Part I: Analysis and Predictions," Technical Report AFWAL-TR-80-2090, Air Force Systems Command, Wright-Patterson Air Force Base, October 1980.

5. Tsuchiya, T. and Murthy, S.N.B., "Water Ingestion into Axial Flow Compressors Part II: Computer Program" Technical Report AFWAL-TR-80-2090, Air Force Systems Command, Wright-Patterson Air Force Base, December 1980.

6. Murthy, S.N.B., Tsuchiya, T., Ehresman, C.M. and Richards, D., "Water Ingestion into Axial Flow Compressors Part III: Experimental Results and Discussion," Technical Report AFWAL-TR-80-2090, Air Force Systems Command, Wright-Patterson Air Force Base, July 1981.

7. Tsuchiya, T., "Effect of Water Ingestion into Axial Flow Compressors," Ph.D. Dissertation at Purdue University, December 1981.

8. Lieblein, S., "Loss and Stall Analysis of Compressor Cascades," Jr. of Basic Engineering, Transaction of the ASME, September 1959.

9. Swan, W.C., "A Practical Method of Predicting Transonic-Compressor Performance," Jr. of Engineering, Transaction of the ASME, July 1961

10. Collier, J.G. and Wallis, G.B., Two-Phase Flow and Heat Transfer, Vol. II, p. 405, Department of Mechanical Engineering, Stanford University, Stanford, California, 1967.

11. Holman, J.P., Heat Transfer, p. 427, McGraw-Hill, New York, 1976.

12. Zucrow, M.J. and Hoffman, J.D., Gas Dynamics, Vol. 1, pp. 55-57, John Wiley & Sons, New York, 1976.

# APPENDIX 1

## DETAILS OF COMPRESSOR USED FOR DEMONSTRATION OF CODE

The compressor utilized for demonstrating the application of the NASA-WISGSK Code is the so-called Test Compressor consisting of the six axial-flow stages of the ALLISON T63-A-5 engine compressor. The Test Compressor has been designed and built such that various stages of the compressor can be assembled and tested. Thus the first two, the intermediate two or the last two stages can be tested if desired, as well as the unit with all of the six stages. Only the 6-stage unit has been used in the current tests.

The first stage of the Test Compressor is preceded by an inlet guide vane row which imparts swirl to the inlet air. The relative Mach number of the incoming air at the rotor inlet is thereby reduced as far as permissible without causing inlet blockage. The axial componet features unshrouded rotors, cantilever stators, and double circular arc blading in all stages. The values of T-63 compressor design velocity diagram are presented in Table A.1.1. Table A.1.3 and A.1.4 present the hardware geometry and aerodynamic design data for rotor and stator, respectively.

Figure A.1.1. to Figure A.1.6 show the stage performance characteristics of Test Compressor supplied by the manufacturer. In each of the figures, the equivalent pressure ratio, $\psi$ , equivalent temperature ratio, $\tau$ , and stage adiabatic efficiency, $\eta$ , are presented in terms of flow coefficient, $\phi$ . The definitions of these parameters are as follows:

(i) flow coefficient: $\phi$

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio: $\psi$

$$\psi = \left[ \left(\frac{U_{tip}^2}{T_{01}}\right)_D \left(\frac{T_{01}}{U_{tip}^2}\right) \left[ \left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right] + 1 \right]^{\frac{\gamma}{\gamma-1}}$$

(iii) equivalent temperature ratio:

$$\tau = \left(\frac{U_{tip}}{T_{01}}\right)^2_D \cdot \left(\frac{\Delta T_0}{U^2_{tip}}\right)$$

(iv) stage adiabatic efficiency:

$$\eta = T_{01}\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]\frac{1}{\Delta T_0} = (\psi^{\frac{\gamma-1}{\gamma}} - 1)/\tau$$

where $\Delta T_0$ is stage total temperature rise, $P_0$ total pressure, $T_0$ total temperatures, $V_z$ axial velocity, $U_{tip}$ blade tip wheel speed, $\gamma$ specific heat ratio. The subscripts 1 and 2 mean inlet and outlet, respectively, and D design value.

Figure A.1.7 shows overall performance characteristics of Test Compressor supplied by the manufacturer. The performance parameters are the following:

(1) Corrected mass flow rate $= \frac{m\sqrt{\theta}}{\delta}$

where $m$ = mass flow rate

$P_{01}$ = compressor inlet pressure

$T_{01}$ = compressor inlet temperature

$\theta = T_{01}/T_{ref}$

$\delta = P_{01}/P_{ref}$

$T_{ref} = 58.7^oF\ (15.2^oC)$

$P_{ref} = 14.7$ psi $(1.0132 \times 10^5 N/m^2)$

(2) Corrected speed $= \frac{N}{\sqrt{\theta}}$

where N = rotor speed (RPM)

(3) Overall total pressure ratio $= P_{02}/P_{01}$

where $P_{01}$= compressor inlet total pressure

$P_{02}$= compressor outlet total pressure

(4) Overall adibatic efficiency $= \eta = \frac{T_{01}}{\Delta T_0}\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$

where $T_{01}$= compressor inlet total temperature

$\Delta T_0$ = compressor total temperature rise

$P_{02}/P_{01}$ = overall total pressure ratio

$\gamma$ = ratio of specific heats

TABLE A.1.1.

TEST COMPRESSOR DESIGN VELOCITY DIAGRAM VALUES

| Stage | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| R | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 | |
| U | 963.5 | 963.5 | 963.5 | 963.5 | 963.5 | 963.5 | |
| $V_{z1}$ | 508.4 | 544.1 | 547.0 | 554.9 | 554.1 | 543.7 | |
| $V_{\theta 1}$ | 236.5 | 310.0 | 365.1 | 349.3 | 338.8 | 333.8 | |
| $W_{\theta 1}$ | 727.0 | 653.5 | 598.4 | 614.2 | 624.7 | 629.9 | Rotor Inlet |
| $\alpha_1$ | 25.0 | 29.7 | 33.7 | 32.2 | 31.6 | 31.5 | |
| $\beta_1$ | 54.9 | 50.3 | 47.6 | 47.9 | 48.5 | 49.3 | |
| $M_{1abs}$ | 0.513 | 0.563 | 0.578 | 0.560 | 0.538 | 0.512 | |
| $M_{1rel}$ | 0.812 | 0.765 | 0.713 | 0.707 | 0.692 | 0.658 | |
| $V_{z2}$ | 507.0 | 554.9 | 551.0 | 554.5 | 548.9 | 544.6 | |
| $V_{\theta 2}$ | 405.2 | 501.3 | 598.8 | 614.6 | 625.1 | 630.3 | |
| $W_{\theta 2}$ | 558.3 | 462.2 | 364.7 | 348.9 | 338.4 | 333.2 | Rotor Outlet |
| $\alpha_2$ | 38.6 | 42.1 | 47.4 | 47.9 | 48.7 | 49.2 | |
| $\beta_2$ | 47.8 | 39.8 | 33.6 | 32.2 | 31.7 | 31.5 | |
| $M_{2abs}$ | 0.588 | 0.665 | 0.706 | 0.698 | 0.680 | 0.660 | |
| $M_{2rel}$ | 0.683 | 0.643 | 0.574 | 0.552 | 0.528 | 0.506 | |

Note: Symbols for Table A.1.1 are provided in Table A.1.2.

TABLE A.1.2

SYMBOLS FOR TEST COMPRESSOR DESIGN VELOCITY DIAGRAM VALUES

| | |
|---|---|
| R | Radius, inches |
| U | Rotor speed at R, ft/sec. |
| $V_z$ | Air axial velocity, ft/sec. |
| $V_\theta$ | Air absolute tangential velocity, ft/sec. |
| $W_\theta$ | Air relative tangential velocity, ft/sec. |
| $\alpha$ | Air absolute flow angle, degrees |
| $\beta$ | Air relative flow angle, degrees |
| M | Mach number |
| Subscript | |
| 1 | rotor inlet |
| 2 | rotor outlet |
| abs | absolute |
| rel | relative |

TABLE A.1.3

TEST COMPRESSOR DESIGN DATA (ROTOR)

| Stage | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Radius | R | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 |
| Chamber Angle | θ | 22.6 | 15.9 | 18.0 | 19.7 | 20.9 | 22.0 |
| Stagger | γ | 46.1 | 42.3 | 36.5 | 36.1 | 36.0 | 36.3 |
| Incidence | i | 0.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Deviation | δ | 7.3 | 5.4 | 6.0 | 6.0 | 6.1 | 6.2 |
| Chord | c | 0.605 | 0.554 | 0.534 | 0.510 | 0.483 | 0.456 |
| Solidity | σ | 0.713 | 0.815 | 0.787 | 0.941 | 0.997 | 1.075 |
| Max. Thickness | t | 0.036 | 0.039 | 0.037 | 0.036 | 0.034 | 0.032 |
| Thickness-Chord Ratio | t/c | 0.060 | 0.070 | 0.070 | 0.070 | 0.070 | 0.070 |
| No. of Blades | n | 16 | 20 | 20 | 25 | 28 | 32 |

Note: R, c, t in (inches) and θ, γ, δ, i in (degrees)

TABLE A.1.4

TEST COMPRESSOR DESIGN DATA (STRATOR)

| Stage | | IGV | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| Radius | R | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 | 2.161 |
| Camber Angle | θ | 31.7 | 22.4 | 25.6 | 26.2 | 24.4 | 24.7 | 17.3 |
| Stagger | γ | -15.9 | 31.3 | 36.3 | 36.6 | 36.8 | 37.4 | 42.6 |
| Incidence | i | 0.0 | -2.0 | -2.0 | -2.0 | -2.0 | -2.0 | -2.0 |
| Deviation | δ | 6.7 | 9.6 | 5.2 | 8.0 | 7.9 | 7.5 | 5.6 |
| Chord | c | 1.395 | 0.442 | 0.412 | 0.412 | 0.412 | 0.412 | 0.412 |
| Solidity | σ | 0.719 | 0.456 | 0.789 | 0.850 | 0.972 | 1.093 | 0.910 |
| Max. Thickness | t | 0.170 | 0.040 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 |
| Thickness-Chord Ratio | t/c | 0.122 | 0.09 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| No. of Blades | n | 7 | 14 | 26 | 28 | 32 | 36 | 30 |

Note: R, c, t in (inches) and θ, γ, δ, i in (degrees)

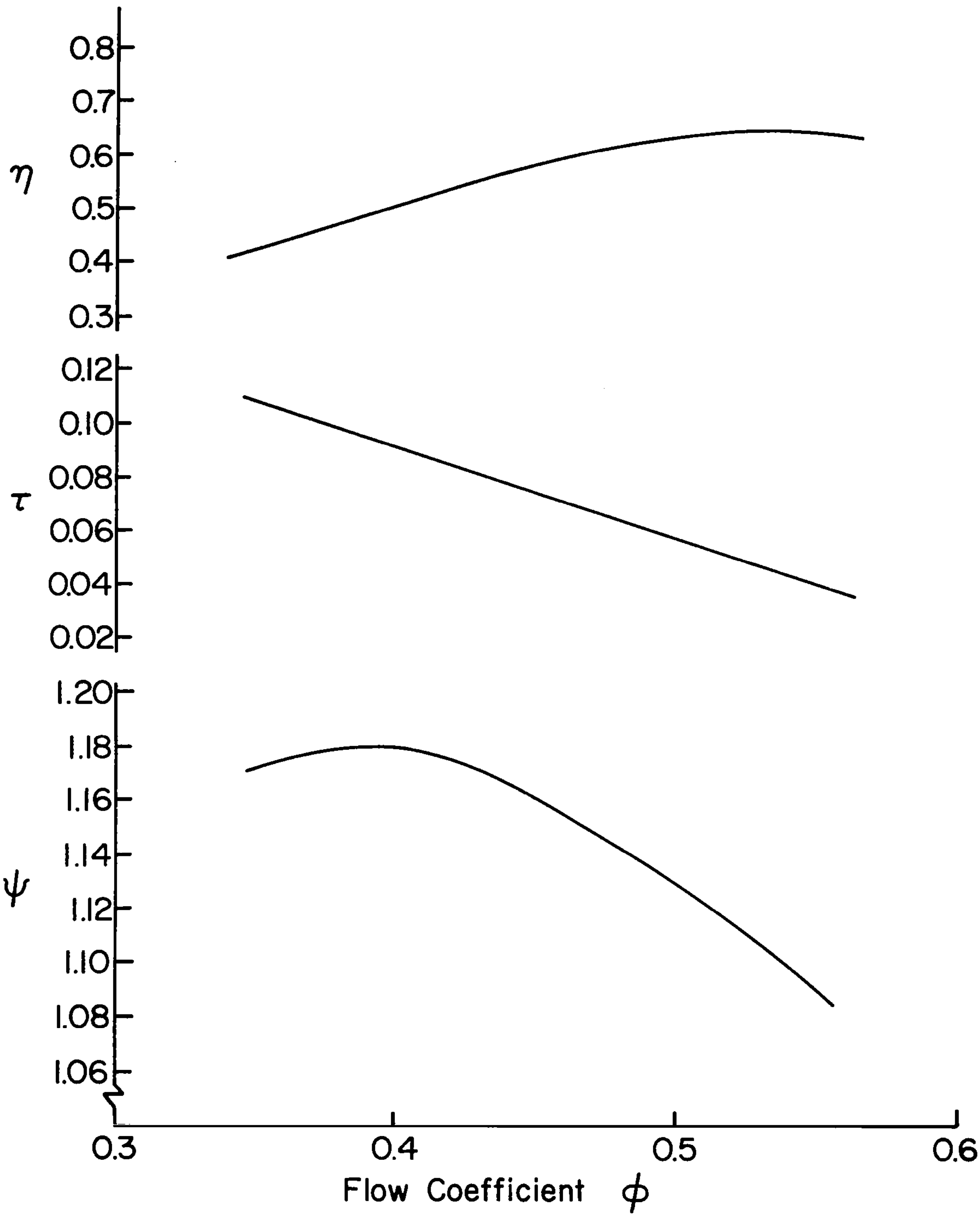


Figure A.1.1 Stage Characteristics of Test Compressor (1st Stage)

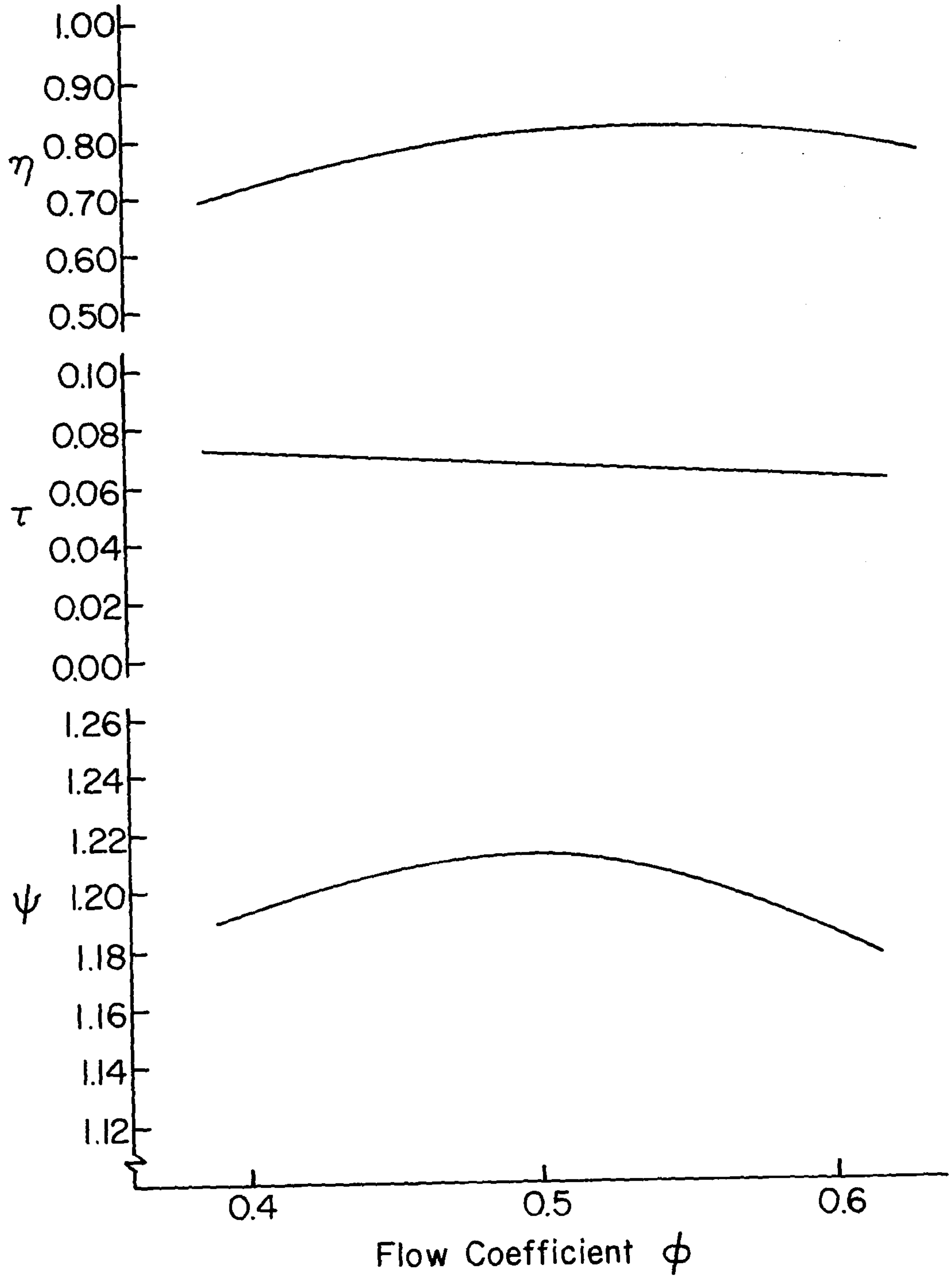


Figure A.1.2 Stage Characteristics of Test Compressor (2nd Stage)

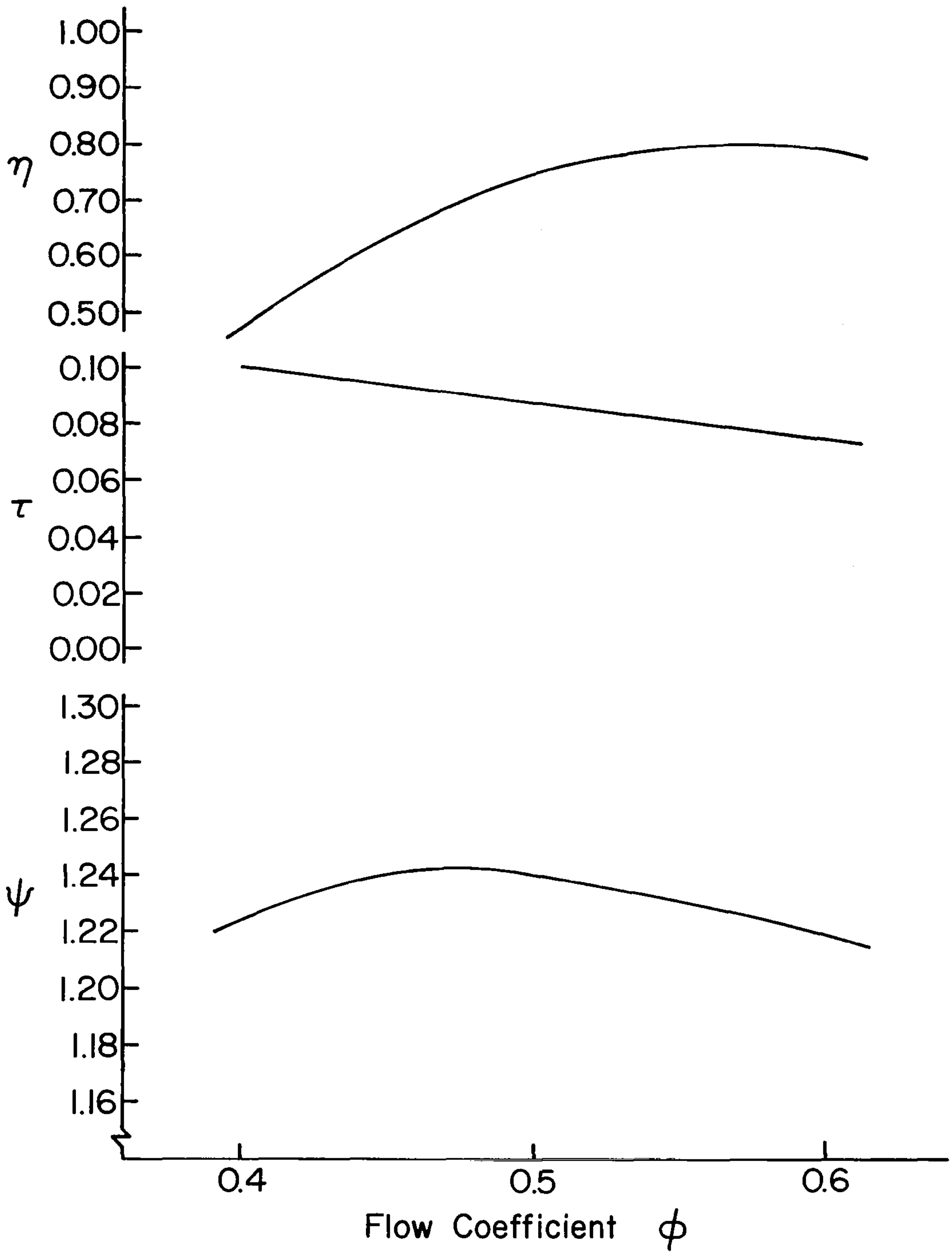


Figure A.1.3 Stage Characteristics of Test Compressor (3rd Stage)

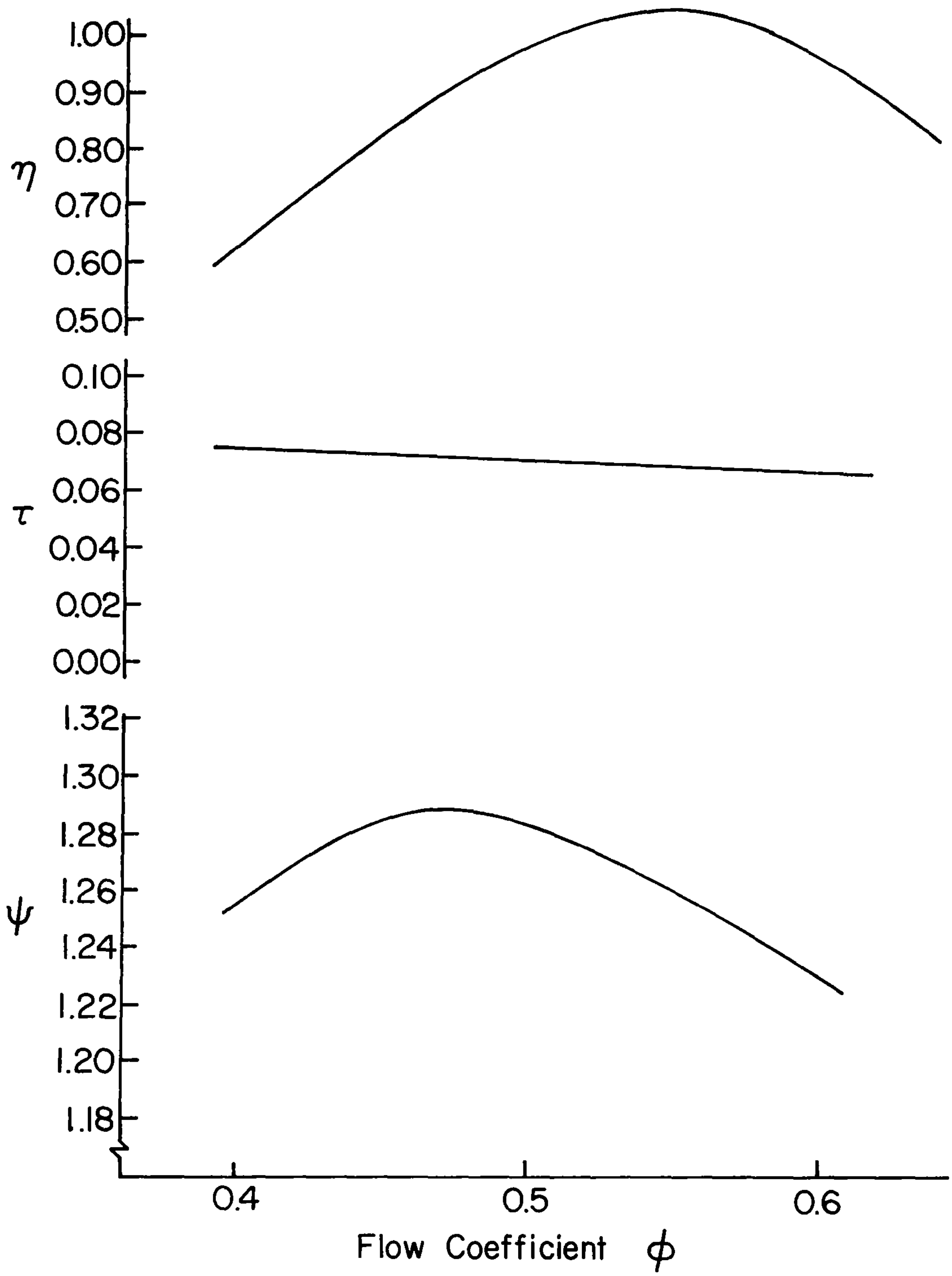


Figure A.1.4 Stage Characteristics of Test Compressor (4th Stage)

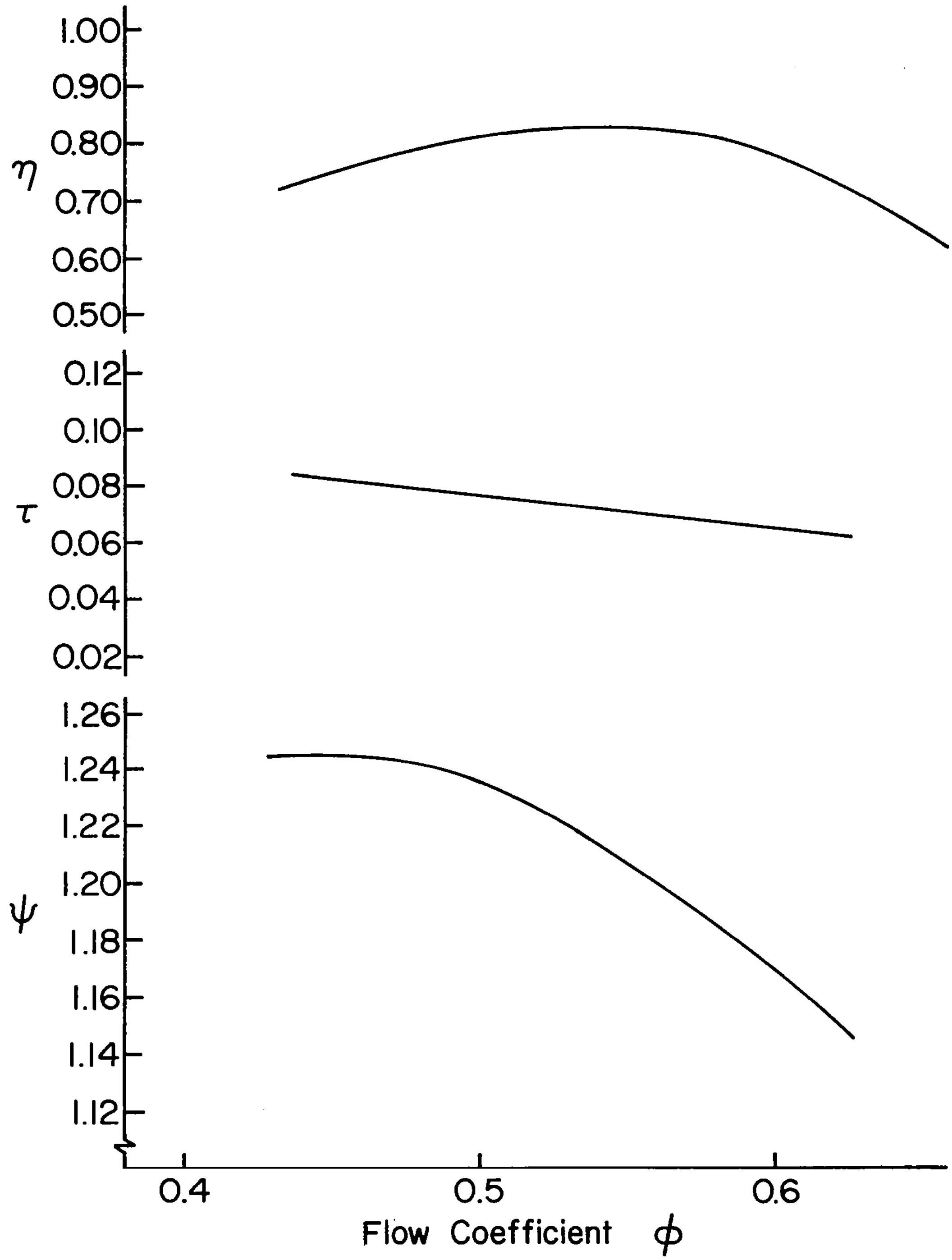


Figure A.1.5 Stage Characteristics of Test Compressor (5th Stage)

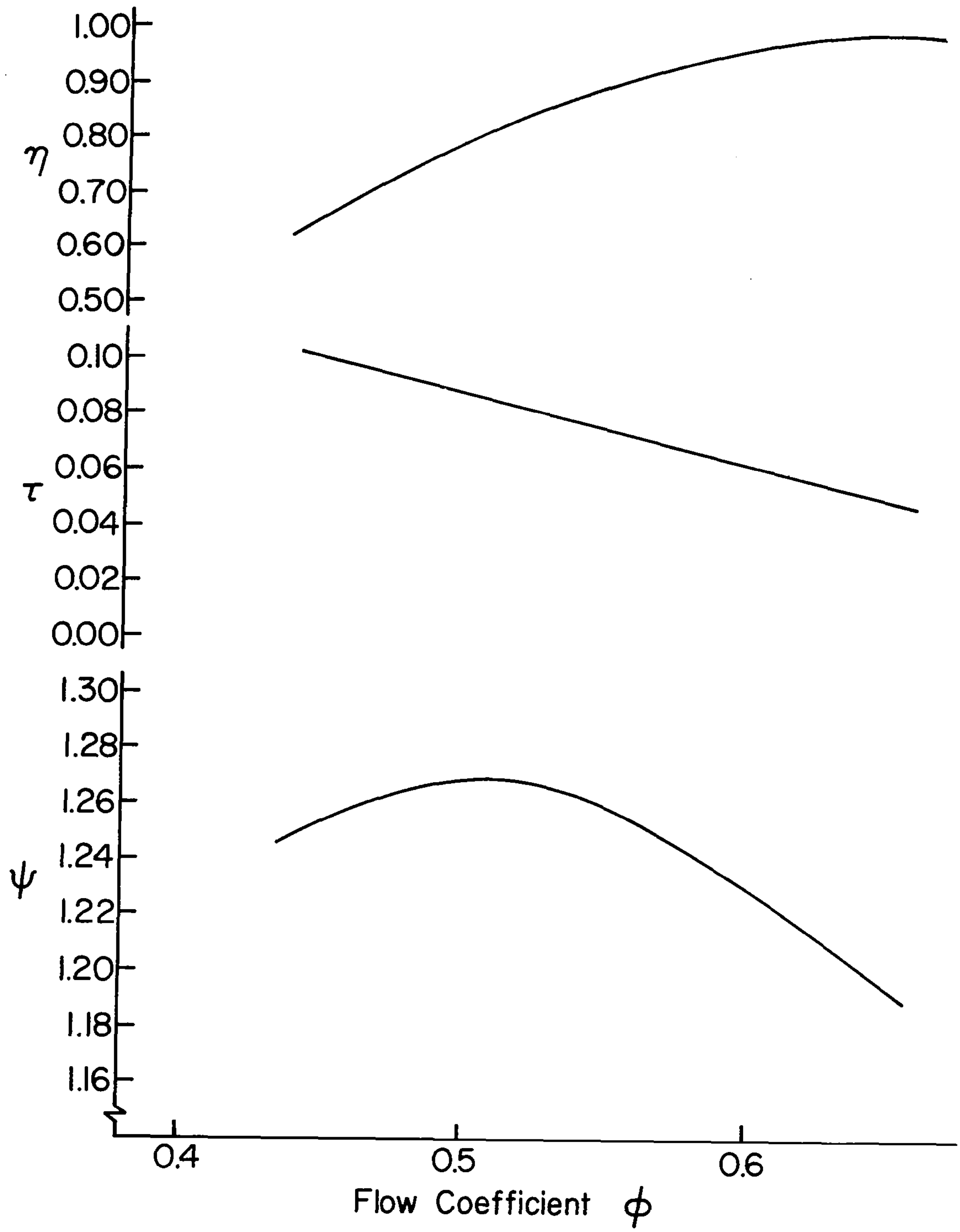


Figure A.1.6 Stage Characteristics of Test Compressor (6th Stage)

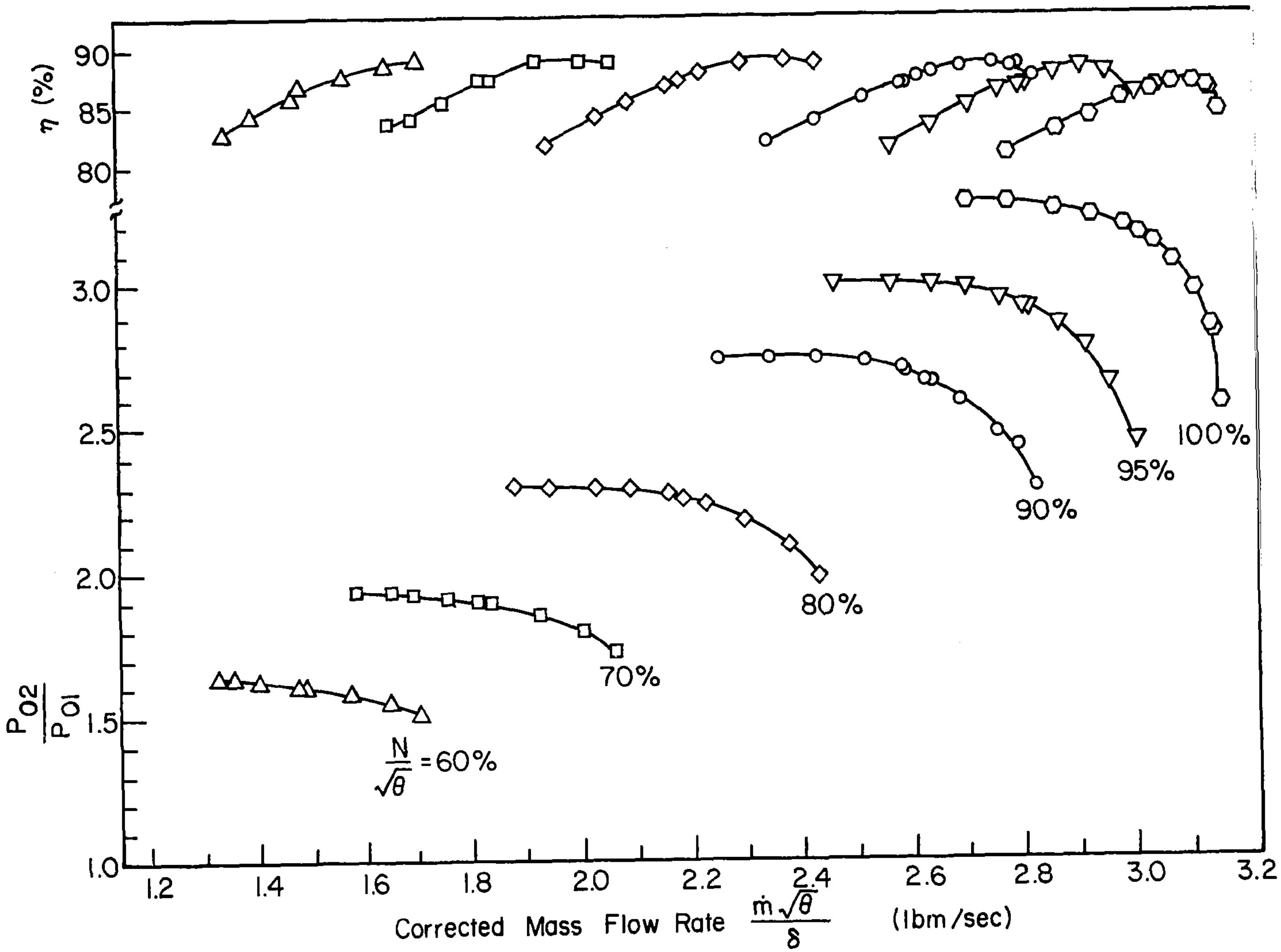


Figure A.1.7 Overall Performance of Test Compressor

# APPENDIX 2

## DETAILED DESCRIPTION OF SUBROUTINES AND EXTERNAL FUNCTIONS

Each of the subroutines and external functions is presented as follows: (1) Description, (2) Input variables, (3) Output variables, and (4) Usage.

### SUBROUTINE WICSPD

(1) Description:

The subroutine WICSPD is used for the calculation of design point performance. The properties obtained in this subroutine become reference properties for calculation of off-design performance.

(2) Input Variables:

| | |
|---|---|
| AMASS | mass flow rate |
| ISTAGE | stage at which performance calculation is carried out |

(3) Output Variables:

none

(4) Usage:

CALL WICSPD (AMASS, ISTAGE)

### SUBROUTINE WICCEN

(1) Description:

The subroutine WICCEN is used for the calculation of spanwise replacement of droplets due to centrifugal action.

Three forces act on a droplet moving through a fluid:
(1) the external force consisting of gravitational and

centrifugal forces; (2) the buoyancy force, which acts parallel to the external force, but in the opposite direction; and (3) the drag force, which appears whenever there is relative motion between the droplet and the fluid, and acts parallel to the direction of motion but in the opposite direction. In the present case, the direction of motion of a droplet relative to the fluid is not parallel to the direction of the external and buoyant forces, and therefore the drag force makes an angle with the other two forces. However, under the one-dimensional approximation, the lines of action of all forces acting on the droplet are co-linear and therefore the forces may be added in obtaining a balance of momentum, as follows:

$$\frac{m}{g_c}\frac{du}{dt} = F_e - F_b - F_D$$

where $F_e$, $F_b$ and $F_D$ are the external, buoyance and drag forces respectively.

The external force can be expressed as the product of mass and acceleration, $a_e$, of the droplet due to this force, and therefore

$$F_e = \frac{m}{g_c} a_e.$$

In the present case, because of the large rotor speeds, the centrifugal acceleration is far larger than the gravitational acceleration. Thus

$$a_e = r\omega^2$$

where r is the radius and $\omega$, the angular velocity. The acceleration can also be written as follows:

$$a_e = V_\theta^2/r$$

where $V_\theta$ is the circumferential velocity of the droplet. For droplets passing through a rotor blade passage, the

circumferential component of the relative velocity, $W_\theta$, should be used in place of $V_\theta$. When there is a large change in whirl velocity between the inlet and outlet of a blade row, a mean value of velocity may be more applicable.

The buoyancy force is, by Archimedes' Principle, the product of the mass of the fluid displaced by the droplet and the acceleration from the external force. The mass of fluid displaced is $(m/\rho_w)\rho_g$, where $\rho_w$ is the density of water and $\rho_g$ is the density of the surrounding fluid. The buoyancy force is then given

$$F_b = m\rho_g a_e/\rho_w g_c.$$

The drag force is expressed by the relation,

$$F_d = C_D \frac{\rho_g u^2}{2g_c} A_p$$

where $C_D$ is the drag coefficient and $A_p$ is the projected area of the droplet measured in a plane perpendicular to the direction of motion of the droplet. The drag coefficient $C_D$ can be expressed in a general form as follows:

$$C_D = b_1/Re^n$$

where Re is the Reynolds number based on relative velocity between gas and droplet. The constants $b_1$ and n are as follows:

$b_1 = 24.0$, $n = 1.0$ when $Re < 1.9$
$b_1 = 18.5$, $n = 0.6$ when $1.9 < Re < 500$
$b_1 = 0.44$, $n = 0.0$ when $500 < Re < 200{,}000$.

The equation of droplet motion then becomes the following:

$$\frac{du}{dt} = A/r - Bu^{2-n}$$

where

$$A = (W_\theta)^2_{ave} \cdot (1 - \rho_g/\rho_w),$$

$B = 3u^n b_1 \rho_g{}^{1-n}/4\rho_w D^{1+n}$, and

D being the average droplet diameter. Over a small time interval, the equation of motion can be written as follows:

$\Delta u = (A/r - Bu^{2-n})\Delta t.$

This equation can be used to determine the radial location of a droplet in a stage as follows:

(i) Select the initial values for $u_1$ and $r_1$.

(ii) Calculate the Reynolds number to determine the values of $b_1$ and n.

(iii) Calculate A and B.

(iv) Calculate the change of u during time interval $\Delta t$.

(v) Calculate the new velocity $u_2$.

$$u_2 = u_1 + \Delta u$$

(vi) Calculate the change in location of droplet in terms of $\Delta r$.

$$\Delta r = (u_1 + u_2)/2.0 \cdot \Delta t$$

(vii) Calculate the new radial location.

$$r_2 = r_1 + \Delta r$$

(viii) Repeat the calculation for new value of $u_2$ and $r_2$ and progressively extend the calculation.

The time interval should be sufficiently small in order to obtain reasonable accuracy. As stated in Section 2.1.3 in Chapter II of Reference 4, the length between the leading and trailing edges of a blade is divided into ten steps. The time interval $\Delta t$ is then given by the relation, namely

$$\Delta t = \frac{\text{chord}}{V} \times \frac{1}{10}$$

where V is the velocity of mixture in the blade passage.

(2) Input Variables:

RZERO droplet spanwise location at rotor inlet

UZERO droplet spanwise velocity at rotor inlet

| | |
|---|---|
| DD | droplet diameter |
| VZ | axial velocity |
| DELZZ | axial length of a stage |
| ALFAAV | average flow angle |
| FN | rotor blade rotational speed |
| IRS | index for rotor or stator |
| RHOGAS | density |
| RHUB | radius at hub |
| XG | mass fraction of gas phase |
| XA | mass fraction of dry air |
| XVV | mass fraction of vapor |
| XCH4 | mass fraction of methane |
| RTIPIN | radius at blade tip |

(3) Output Variables:

| | |
|---|---|
| R2 | droplet spanwise location blade outlet |
| U2 | droplet spanwise velocity at blade outlet |
| ITIP | index for droplet spanwise location |
| VZTIME | time in which flow pass through a stage |

(4) Usage:

```
CALL WICCEN (RZERO, VZERO, DD, VZ, DELZZ, ALFAAV, FN, IRS,
             RHOGAS, RHUB, R2, U2, ITIP, VZTIME, XG, XA, XVV,
             XCH4, RTIPIN)
```

SUBROUTINE WICDMS

(1) Description:

The subroutine WICDMS is used for the calculation of amount of small droplets which is centrifuged.

(2) Input Variables:

| | |
|---|---|
| IPRINT | index for printout |
| IRAD | index for spanwise location |
| AMASW1 | mass flow rate of water at rotor inlet |
| AMASWT | mass flow rate of droplet |
| AMASW | mass flow rate of droplet |
| R1 | droplet spanwise location rotor inlet |

| | |
|---|---|
| R2 | droplet spanwise location at rotor outlet |
| STAREA | streamtube area |
| RSTAVE | radius of streamtube at its center |
| RTIP | radius at blade tip |

(3) Output Variables:

| | |
|---|---|
| DMIN | amount of water that is centrifuged and enters into a streamtube |
| DMOUT | amount of water that is centrifuged and leaves from a streamtube |
| AMASW2 | mass fraction of water at rotor outlet after correction for centrifugal action |
| DELMAS | net amount of water that is centrifuged |

(4) Usage:

```
CALL WICDMS (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1, R2,
            STAREA, RSTAVE, RTIP, DMIN, DMOUT, AMASW2, DELMAS)
```

## SUBROUTINE WICDML

(1) Description:

The subroutine WICDML is used for the calculation of amount of large droplets which is centrifuged.

(2) Input Variables:

| | |
|---|---|
| IPRINT | index for printout |
| IRAD | index for spanwise location |
| AMASW1 | mass flow rate of water at rotor inlet |
| AMASWT | mass flow rate of droplet |
| AMASW | mass flow rate of droplet |
| R1 | droplet spanwise location rotor inlet |
| R2 | droplet spanwise location at rotor outlet |
| STAREA | streamtube area |
| RSTAVE | radius of streamtube at its center |
| RTIP | radius at blade tip |

(3) Output Variables:

DMIN — amount of water that is centrifuged and enters into a streamtube

DMOUT — amount of water that is centrifuged and leaves from a streamtube

AMASW2 — mass fraction of water at rotor outlet after correction for centrifugal action

DELMAS — net amount of water that is centrifuged

(4) Usage:

```
CALL WICDML (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1, R2,
            STAREA, RSTAVE, RTIP, DMIN, DMOUT, AMASW2, DELMAS)
```

SUBROUTINE WICMAC

(1) Description:

Subroutine WICMAC calculates the Mach number in the gas-water droplet mixture. First the acoustic speed in gaseous phase is determined by iteration as follows:

(i) Assume Mach number and calculate static temperature and density.

$$t = \left(1 + \frac{\gamma-1}{2}M^2\right)^{-1} T_{01}$$

$$\rho = \left(1 + \frac{\gamma-1}{2}M^2\right)^{-1/(\gamma-1)} P_{01}/RT_{01}$$

(ii) Calculate acoustic speed in gaseous phase

$$a_g = (\gamma R t g_c)^{0.5}$$

(iii) Calculate the axial velocity

$$V_z = \dot{m}/\rho A$$

(iv) Calculate absolute velocity

$$V_1 = V_3/\cos\alpha_1$$

(v) Calculate Mach number

$$M_1 = V_1/a_g$$

Compare the calculated Mach number with the assumed value in (i). Iterate steps (i) to (v) until the desired accuracy is obtained. After determining the acoustic speed in gaseous phase, Function WICASD is called to determine the acoustic speed in droplet-laden gas flow.

(2) Input Variables:

| | |
|---|---|
| ISTAGE | stage number |
| AMASSM | mixture mass flow rate |
| TO1G | total temperature of gaseous phase |
| PRES | total pressure |
| XW1 | total water content |
| ALFA | stator outlet angle of the previous stage |
| RMIX | gas content of gaseous phase |
| CPMIX | specific heat at constant pressure for gaseous phase |

(3) Output Variables:

| | |
|---|---|
| M | Mach number |
| VZ | axial velocity |
| C | acoustic speed in mixture |

(4) Usage:

```
CALL WICMAC (ISATE, AMASSM, TO1G, PRES, M, VZ, C, XW1, ALFA,
             RMIX, CPMIX)
```

FUNCTION WICASD

(1) Description:

Function WICASD calculates the acoustic speed in droplet-laden gas flow. The following equation is used (Ref. 10).

$$a = \left[\left\{(1-\sigma_v)\rho_g + \sigma_v\rho_w\right\}\left\{\frac{1-\sigma_v}{\rho_g a_g} + \frac{\sigma_v}{\rho_w a_w^2}\right\}\right]^{-\frac{1}{2}}$$

where

$a_g$ = acoustic speed in gaseous phase

$a_w$ = acoustic speed in water
$\rho_g$ = density of gaseous phase
$\rho_w$ = density of water
$\sigma_v$ = particulate liquid volume fraction
$x_w$ = particulate liquid mass fraction
$\sigma_v = x_w\rho_g/\{\rho_w - x_w(\rho_w - \rho_g)\}$

(2) Input Variables:

| | |
|---|---|
| XW | total water content |
| RHOG | density of gas phase |
| CG | acoustic speed of gaseous phase |

(3) Output Variable:

| | |
|---|---|
| WICASD | acoustic speed in gas-water droplet mixture |

(4) Usage:

WICASD (XW, RHOG, CG)

SUBROUTINE WICIRS

(1) Description:

Subroutine WICIRS is called at outlet of rotor and performs the calculation of droplet impingement and rebound in rotor passage for small droplet.

(2) Input Variables:

| | |
|---|---|
| ISTAGE | stage number |
| RTIPIN | blade tip radius |
| XW1 | mass fraction of small droplet |
| XG | mass fraction of gaseous phase |
| RHOG1 | density of gaseous phase |
| BETA1 | rotor inlet relative flow angle |
| W1 | rotor inlet relative velocity |

(3) Output Variables:

| | |
|---|---|
| WW1 | amount of water that impacts stagnation region of blade |
| WW2 | amount of water that impacts aft of blade |
| WW | total amount of water that impacts blade |

(4) Usage:

CALL WICIRS (ISTAGE, RTIPIN, XW1, XG, RHOG1, BETA1, W1, WW1, WW2, WW)

SUBROUTINE WICIRL

(1) Description:

Subroutine WICIRL is called at outlet of rotor and performs the calculation of droplet impingement and rebound in rotor passage for large droplet.

(2) Input Variables:

| | |
|---|---|
| ISTAGE | stage number |
| RTIPIN | blade tip radius |
| XW1 | mass fraction of large droplet |
| XG | mass fraction of gaseous phase |
| RHOG1 | density of gaseous phase |
| BETA1 | rotor inlet relative flow angle |
| W1 | rotor inlet relative velocity |

(3) Output Variables:

| | |
|---|---|
| WW1 | amount of water that impacts upper surface of blade |
| WW2 | amount of water that impacts lower surface of blade |
| WW | amount of water that impacts blade surface |

(4) Usage:

CALL WICIRL (ISTAGE, RTIPIN, XW1, XG, RHOG1, BETA1, W1, WW1, WW2, WW)

SUBROUTINE WICISS

(1) Description:

Subroutine WICISS is called outlet of stator and performs the calculation of droplet impingement and rebound in stator passage for small droplet.

(2) Input Variables:

| | |
|---|---|
| ISTAGE | stage number |
| RTIPIN | blade tip radius |
| XW | mass fraction of small droplet |
| XG | mass fraction of gaseous phase |
| RHOG1 | density of gaseous phase |
| ALFA2 | stator inlet absolute flow angle |
| W1 | stator inlet absolute velocity |

(3) Output Variables:

| | |
|---|---|
| WW1 | amount of water that impacts stagnation region of blade |
| WW2 | amount of water that impacts off of blade |
| WW | total amount of water that impacts the blade |

(4) Usage:

```
CALL WICISS (ISTAGE, TRIPIN, XW, XG, RHOG1, ALFA2, W1, WW1,
             WW2, WW)
```

SUBROUTINE WICISL

(1) Description:

Subroutine WICISL is called at outlet of stator and performs the calculation of droplet impingement and rebound in stator passage for large droplet.

(2) Input Variables:

| | |
|---|---|
| ISTAGE | stage number |
| RTIPIN | blade tip radius |
| XW | mass fraction of |
| XG | mass fraction of gaseous phase |
| RHOG1 | density of gaseous phase |
| ALFA2 | stator inlet absolute flow angle |
| W1 | stator inlet absolute velocity |

(3) Output Variables:

| | |
|---|---|
| WW1 | amount of water that impacts upper surface of blade |

| | |
|---|---|
| WW2 | amount of water that impacts lower surface of blade |
| WW | total amount of water that impacts on blade surface |

(4) Usage:

CALL WICISL (ISTAGE, RTIPIN, XW, XG, RHOG1, ALFA2, W1, WW1, WW2, WW)

SUBROUTINE WICWAK

(1) Description:

Subroutine WICWAK is called at rotor outlet and stator outlet, and calculates the droplet size of water that is re-entrained at trailing edge of rotor and stator blades.

(i) Assume a value for a droplet diameter, d, that is re-entrained into wake.

(ii) Calculate the stability number, SN.

$$SN = \mu_f^2/\rho_g \sigma d g_c$$

(iii) Calculate the critical Weber number

$$W_e = 12 \{1 + (SN)^{0.36}\}$$

(iv) Calculate the largest stable droplet diameter

$$d_{max} = \frac{W_e}{\rho_g} \frac{\sigma g_c}{V_g^2}$$

(v) Compare the assumed droplet diameter with the calculated one. Iterate entire steps until the satisfactory agreement is obtained.

(2) Input Variables:

| | |
|---|---|
| RHOG | density of gaseous phase |
| V | velocity of gaseous phase for small droplet or relative velocity between droplet and gaseous phase for large droplet |

(3) Output Variables:

| | |
|---|---|
| DWAKE | droplet size that re-entrained at trailing edge in($ft^3$) |
| DWAKEM | droplet size that re-entrained at trailing edge in($\mu m$) |

(4) Usage:

CALL WICWAK (RHOG, V, DWAKE, DWAKEM)

SUBROUTINE WICHET

(1) Description:

Subroutine WICHET is called at end of stage to perform the heat transfer calculation between water droplet and gaseous phase. The heat transfer rate can be determined from the following equation:

$$\frac{dh}{dt} = h_h A \ (T_g - T_w)$$

where $h_h$ is the heat transfer coefficient, A, the droplet surface area, $T_w$, the droplet surface temperature, and $T_g$, the temperature of the surrounding gas. The heat transfer coefficient can be expressed as follows:

$$h_h = \frac{k_a}{D_d} \cdot Nu$$

where $k_a$ is the thermal conductivity of air, and Nu, the Nusselt Number. The Nusselt number can be expressed in terms of the dimensionless groups as follows:

$$Nu = 2.0 + 0.6 \ (Re)^{0.50}(Pr)^{0.33}$$

where Re is the Reynolds number based on the relative velocity between the droplet and the surrounding air, and Pr is Prandtl number.

After calculating the temperature rise of the water and gas phase due to the work done by the rotor, the heat transfer calculation is carried out as follows:

(i) Calculate the average droplet diameter, $D_d$.

(ii) Calculate the number of droplets, $N_d$.

$$N_d = \frac{\dot{m}_w}{\rho_w \frac{4}{3}\pi (D_d/2)^3} \cdot \frac{\Delta z}{V_z}$$

where $\dot{m}_w$ is the mass flow rate of water phase, $\rho_w$, the density of water, $V_z$, the axial direction velocity, and $\Delta z$, the axial length of one stage.

(iii) Calculate the droplet surface area, A.

(iv) Calculate the Nusselt number, Nu.

(v) Calculate the heat transfer coefficient, $h_h$.

(vi) Calculate the stage outlet temperature for droplet and gas without heat transfer, that is

$$T_{g_2} = T_{g_1} + (\Delta T_g)_{wk}$$

$$T_{w_2} = T_{w_1} + (\Delta T_w)_{wk}$$

where $(\Delta T_g)_{wk}$ and $(\Delta T_w)_{wk}$ are the temperature rise of gas and water due to work done by rotor.

(vii) Calculate the amount of heat transferred from the gas to the droplet.

$$\Delta H = h_h A\, (T_{g_2} - T_{w_2})$$

(viii) Calculate the temperature rise of the droplet and the temperature drop of the surrounding gas.

$$(\Delta H_g)_{ht} = \Delta H/m_g C_s$$

$$(\Delta H_w)_{ht} = \Delta H/m_w C_w$$

where $C_w$ is the specific heat for water and $C_s$ is the humid heat for air-water mixture.

(ix) Calculate the stage outlet temperature for droplet and gas.

$$T_{g_2} = T_{g_1} + (\Delta T_g)_{wk} - (\Delta T_g)_{ht}$$

$$T_{w_2} = T_{w_1} + (\Delta T_w)_{wk} + (\Delta T_w)_{ht}$$

(x) Using the temperature calculated in step (ix), repeat the steps (vii) to (ix) until a desired accuracy is obtained.

(2) Input Variables:

| | |
|---|---|
| TG1 | temperature of gaseous phase at stage inlet |
| TG3 | temperature of gaseous phase at stage outlet |
| TW1 | temperature of droplet at stage inlet |
| TW3 | temperature of droplet at stage outlet |
| DAVEN2 | droplet nominal diameter at stage inlet |
| DAVEN | droplet nominal diameter at stage outlet |
| DELZI | length of stage |
| VZ | axial velocity |
| WMASS1 | mass flow rate of water |
| VMASS1 | mass flow rate of water vapor |
| AMASS | mass flow rate of dry air |
| CHMASS | mass flow rate of methane |
| DPG | specific heat constant pressure to gaseous phase |
| CPW | specific heat of water |
| RE | Reynolds number based on relative velocity between droplet and gaseous phase |

(3) Output Variables:

| | |
|---|---|
| DELIGH | temperature drop in gaseous phase due to heat transfer between water droplet and gaseous phase |
| DELTWH | temperature rise in droplet due to heat transfer between water droplet and gaseous phase |

(4) Usage:

```
CALL WICHET (TG1, TG3, TW3, DAVEN2, DAVEN, DELZI, VZ, WMASS1,
            VMASS1, AMASS, CHMASS, CPG, CPW, DELIGH, DELTWH,
            RE)
```

SUBROUTINE WICMAS

(1) Description:

Subroutine WICMAS is called at end of stage to perform the mass transfer calculation between water droplet and gas phases.

The mass transfer rate can be calculated by the following equation:

$$\frac{dm}{dt} = h_m A \, (C_{wb} - C_w)$$

where $h_m$ is the mass transfer coefficient, $A$, the droplet surface area, $C_{wb}$, the water vapor concentration at droplet surface, and $C_w$, the water vapor concentration in fluid flow around droplet.

Since the density represents the mass concentration, and the vapor is almost a perfect gas, the mass transfer rate can be expressed in terms of vapor pressure as follows:

$$\frac{dm}{dt} = h_m A \, (\rho_{wb} - \rho_w)$$

or

$$\frac{dm}{dt} = h_m A \left( \frac{P_{wb}}{T_{wb}} - \frac{P_w}{T_w} \right) \cdot \frac{1}{R_v}$$

where $R_v$ is the gas constant for water vapor, $P_{wb}$, the vapor pressure at droplet surface, $P_w$, the vapor pressure in fluid flowing around droplet, $T_{wb}$, the vapor temperature at droplet surface, and $T_w$, the vapor temperature in fluid flowing around droplet.

The surface area, $A$, for the droplet cloud is given by the relation,

$$A = \pi D_d^2 N_d$$

where $D_d$ is the average droplet diameter, and $N_d$, the number of droplets.

The mass transfer coefficient, $h_m$, is expressed as follows:

$$h_m = \frac{D_v}{D_d} \cdot Sh$$

A semi-empirical equ~~ati~~on for the diffusion coefficient in gases is given by the following: (Reference 11)

$$D_v = 435.7 \frac{T^{3/2}}{p(V_A{}^{1/3} + V_B{}^{1/3})^2} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{1/2}$$

where $D_v$ is in square centimeters per second, T is in degree Kelvin, p is the total system pressure in newtons per square meter, and $V_A$ and $V_B$ are the molecular volumes of constituents A and B as calculated from the atomic volumes. $M_A$ and $M_B$ are given as follows:

$V_A = V_{air} = 29.9$ $M_A = M_{air} = 28.9$

$V_B = M_{water} = 18.8$ $M_B = M_{water} = 18.0$

When the relative velocity between a single droplet and the surrounding fluid approaches zero, the following relationship is used to determine the mass transfer rate:

$Sh = 2.0.$

Mass transfer rates increase with increase in relative velocity between the droplet and the surrounding air due to the additional mass transfer caused by the convection in the boundary layer around the droplet. The mass transfer coefficient from a spherical droplet can be expressed in terms of dimensionless groups as follows:

$Sh = 2.0 + k\ (Re)^x (Sc)^y$

where Re is the Reynolds number based on relative velocity, which expresses the ratio of inertial force to viscous force, and Sc is the Schmidt number, which expressed the ratio of kinetic viscosity to molecular diffusivity.

There is much discussion over the values of x, y, and k. The form most widely applied is the Ranz and Marshall equation which is

$Sh = 2.0 + 0.6\ (Re)^{0.50} (Sc)^{0.33}$

The procedure for determining the mass transfer rate is as follows:

(i) Calculate the Sherwood number, Sh.

(ii) Calculate the diffusion coefficient, $D_v$.

(iii) Calculate the average droplet size, $D_d$.

(iv) Calculate the mass transfer coefficient, $h_m$.

(v) Calculate the total number of droplets, $N_d$.

(vi) Calculate the total surface area for all droplets.

(vii) Calculate the water vapor pressure at droplet surface, $P_{wb}$, based on the droplet surface temperature, $T_s$.

(viii) Assume the vapor pressure, $p_w$, and set $p_w = (p_w)_a$.

(ix) Calculate the mass transfer rate, $\frac{dm}{dt}$.

(x) Calculate the new value of water mass flow rate.

$$\dot{m}_w = \dot{m}_w - \frac{dm}{dt}$$

(xi) Calculate the new value of vapor mass flow rate.

$$\dot{m}_v = \dot{m}_v + \frac{dm}{dt}$$

(xii) Calculate the specific humidity, W.

$$W = \dot{m}_v/\dot{m}_a$$

where $m_a$ is the air mass flow rate.

(xiii) Calculate the vapor pressure.

(xiv) Compare the calculated value, $(p_w)_c$, with the assumed value $(p_w)_a$.

If $(p_w)_c$ agrees reasonably well with the assumed value $(p_w)_c$ proceed to step (xv). Otherwise, steps (viii) to (xiv) should be repeated.

(xv) Using the determined $p_w$, the mass transfer rate is calculated. Also, the specific humidity can be determined by the following equation:

$$W = 0.6219 \frac{P_w}{P - P_w}$$

(2) Input Variables:

| | |
|---|---|
| HW1 | specific humidity at stage inlet |
| TW1 | temperature of droplet at stage inlet |
| TW2 | temperature of droplet at stage outlet |
| PP1 | pressure of gaseous phase at stage inlet |
| PP2 | pressure of gaseous phase at stage outlet |
| TG1 | temperature of gaseous phase at stage inlet |
| TG2 | temperature of gaseous phase at stage outlet |
| DZ | length of stage |
| VZ | axial velocity |
| DDAVE1 | droplet nominal diameter at stage inlet |
| DDAVE2 | droplet nominal diameter at stage outlet |
| AMASS | mass flow rate of air |
| RE | Reynolds number based on relative velocity between droplet and gaseous phase |
| VMASS1 | mass flow rate of water vapor at stage inlet |
| WMASS1 | mass flow rate of water droplet at stage outlet |

(3) Output Variables:

| | |
|---|---|
| HW2 | specific humidity at stage outlet |
| VMASS2 | mass flow rate of water vapor at stage outlet |
| WMASS2 | mass flow rate of water droplet at stage outlet |
| DMDTAV | average mass transfer rate across stage |

(4) Usage:

```
CALL WICMAS (HW1, TW1, TW2, PP1, PP2, TG1, TG2, DZ, PWB1,
            PWB2, PW1, PW2, VZ, DDAVE1, DDAVE2, HW2, VMASS1,
            VMASS2, WMASS1, WMASS2, DMDTAV, AMASS, RE)
```

FUNCTION WICMTR

(1) Description:

Function WICMTR is called in Subroutine WICMTR and calculates the mass transfer rate.

(2) Input Variables:

| | |
|---|---|
| TTG | temperature of gaseous phase |

| | |
|---|---|
| TTW | temperature of water droplet |
| PPP | pressure of gaseous phase |
| DAVW | droplet nominal diameter |
| VA | axial velocity |
| DZ | length of stage |
| MMASS | mass flow rate of mixture |
| PW | vapor pressure |
| RE | Reynolds number based on relative velocity between droplet and gaseous phase |

(3) Output Variable:

DMDT mass transfer rate

(4) Usage:

WICMTR (TTG, TTW, PPP, DAVE, VZ, DZ, MMASS, PW, RE)

FUNCTION WICPWB

(1) Description:

Function WICPWB calculates the saturation pressure for water vapor as a function of temperature as follows:

$$\log_{10} p_s = A - B/T$$

where units are (Kg/cm$^2$) for $p_s$ and (K) for T. The values of constant A and B are given as follows:

$A = 5.97780$, $B = 2224.4$ when $20^{o}C < T < 100^{o}C$

$A = 5.64850$, $B = 2101.1$ when $100^{o}C < T < 200^{o}C$

$A = 5.45142$, $B = 2010.8$ when $200^{o}C < T < 350^{o}C$

(2) Input Variable:

TWB temperature of gaseous phase

(3) Output Variable:

WICPWB saturation pressure for water vapor

(4) Usage:

WICPWB (TWB)

FUNCTION WICNEW

(1) Description:

Function WICNEW is used to estimate the new trial value in the iteration procedure.

(2) Input Variables:

| | |
|---|---|
| X1 | first trial value |
| Y1 | calculated value corresponds to X1 |
| X2 | second trial value |
| Y2 | calculated value corresponds to X2 |

(3) Output Variable:

| | |
|---|---|
| WICNEW | new trial value |

(4) Usage:

WICNEW (X1, Y1, X2, Y2)

FUNCTION WICTAN

(1) Description:

Function WICTAN(X) is used to obtain the ratio of SINE(X) to COSINE(X), that is, TAN(X).

(2) Input Variable:

| | |
|---|---|
| X | angle |

(3) Output Variable:

| | |
|---|---|
| WICTAN | value of TAN(X) |

(4) Usage:

WICTAN(X)

FUNCTION WICBPT

(1) Description:

Function WICBPT calculates the temperature at boiling point.

(2) Input Variables:

| | |
|---|---|
| TSTAG | temperature |
| PSTAGE | pressure |

(3) Output Variable:

| | |
|---|---|
| WICBPT | temperature at boiling point |

(4) Usage:

WICBPT (TSTAG, PSTAG)

FUNCTION WICSH

(1) Description:

Function WICSH calculates the specific humidity.

(2) Input Variables:

| | |
|---|---|
| TSTAGE | temperature |
| PSTAG | pressure |

(3) Output Variable:

| | |
|---|---|
| WICSH | specific humidity |

(4) Usage:

WICSH (TSTAG, PSTAG)

SUBROUTINE WICSIZ

(1) Description

Subroutine WICSIZ is called at outlet of rotor and stator to determine the nominal droplet sizes. It is assumed that two kinds of droplets exist at inlet of compressor; namely, small droplet and large droplet. However, at trailing edge of each blade, the new droplets are re-entrained into blade wake. The droplets which are larger than DLIMIT are treated as large droplets and droplets which are smaller than DLIMIT are treated as small droplets. Each droplet size weighted based on its mass fraction in determining the nominal droplet size. Therefore, at outlet of each blade row, Subroutine WICSIZ gives two nominal diameters; one for small droplet and one for large droplet. It may be noted that only two classes of droplets are recognized in the model.

(2) Input Variables:

| | |
|---|---|
| WMASSL | mass flow rate of large droplet |

| | |
|---|---|
| WMASSS | mass flow rate of small droplet |
| AMING1 | amount of water which is to be re-entrained into wake, originally small droplet |
| AMING2 | amount of water which is to be re-entrained into wake, originally large droplet and upper part |
| AMING3 | amount of water which is to be re-entrained into wake, originally large droplet and lower part |
| DL | droplet nominal size for large droplet before impingement |
| DS | droplet nominal size for small droplet before impingement |
| D1 | droplet size associated with AMING1 |
| D2 | droplet size associated with AMING2 |
| D3 | droplet size associated with AMING3 |
| DLIMIT | largest droplet diameter which can be treated as small droplet |

(3) Output Variables:

| | |
|---|---|
| AMSLL | mass flow rate of small droplet after re-entrainment |
| AMLGE | mass flow rate of large droplet after re-entrainment |
| DSLL | droplet nominal size for small droplet |
| DLGE | droplet nominal size for large droplet |

(4) Usage:

CALL WICSIZ (WMASSL, WMASSS, AMING1, AMING2, AMING3, DL, DS, D1, D2, D3, DLIMIT, AMSLL, AMLGE, DSLL, DLGE)

SUBROUTINE WICPRP

(1) Description

Subroutine WICPRP determines the flow properties such as gas constant specific heat ratio, and specific heat at constant pressure for the gaseous mixture. The working equations are as follows:

$$R_{mix} = x_a \cdot R_a + x_v \cdot R_v + x_c \cdot R_c$$

$$c_{pmix} = x_a \cdot c_{pa} + x_v \cdot c_{pv} + x_c \cdot c_{pc}$$

$$\gamma_{mix} = (1.0 - \frac{R_{mix}}{c_{pmix} J})^{-1}$$

where

$x_a$ = mass fraction of air in gaseous mixture

$x_v$ = mass fraction of water vapor in gaseous mixture

$x_c$ = mass fraction of methane in gaseous mixture

$x_a + x_v + x_c = 1$

$R_a$ = gas constant of air

$R_v$ = gas constant of water vapor

$R_c$ = gas constant of methane

$R_{mix}$ = gas constant of mixture

$c_{pa}$ = specific heat constant pressure for air

$c_{pv}$ = specific heat constant pressure for water vapor

$c_{pc}$ = specific heat at constant pressure for methane

$c_{pmix}$ = specific heat at constant pressure for mixture

$r_{mix}$ = specific heat ratio for mixture

(2) Input Variables:

| | |
|---|---|
| XAIR | mass fraction of air in gaseous mixture |
| XH2O | mass fraction of water vapor in gaseous mixture |
| XCH4 | mass fraction of methane in gaseous mixture |
| T | temperature of gaseous mixture |

(3) Output Variables:

| | |
|---|---|
| RMIX | gas constant of gaseous mixture |
| CPMIX | specific heat constant pressure for gaseous mixture |
| GAMMA | specific heat ratio of gaseous mixture |
| G1 | value for GAMMA/(GAMMA - 1.0) |
| G2 | value for (GAMMA - 1.0)/2.0 |
| G3 | value for -1.0/(GAMMA - 1.0) |

(4) Usage:

```
CALL WICPRP (XAIR, XH2O, XCH4, T, RMIX, CPMIX, GAMMA, G1, G2,
          G3)
```

FUNCTION WICCPA

(1) Description:

Function WICCPA calculates the specific heat at constant pressure for air as a function of temperature as follows: (Reference 11)

$$c_p = (a + aT = cT^2 + dt^3 + eT^4)R$$

where units are (J/kg-K) for $c_p$, (K) for T, and (J/kg-K) for R. The values of coefficients a, b, c, d, and e are as follows:

$a = 3.65359$
$b = -1.33736 \times 10^{-10}$
$c = 3.29421 \times 10^{-6}$
$d = -1.91142 \times 10^{-9}$
$e = 0.275462 \times 10^{-12}$

(2) Input Variable:

T temperature

(3) Output Variable:

WICCPH specific heat constant pressure

(4) Usage:

WICCPH(T)

FUNCTION WICCPH

(1) Description:

Function WICCPH calculates the specific heat at constant pressure for water vapor as a function of temperature as follows: (Reference 11)

$$c_p = (a + bT + cT^2 + dT^3 + eT^4)R$$

where units are (J/kg-K) for $c_p$, (K) for T, and (J/kg-K) for R. The values of coefficients a, b, c, d, and e are as follows:

$a = 4.07013$
$b = -1.10845 \times 10^{-3}$

$c = 4.15212 \times 10^{-6}$
$d = -2.96374 \times 10^{-9}$
$e = 0.807021 \times 10^{-12}$

(2) Input Variable:
T temperature

(3) Output Variable:
WICCPH specific heat at constant pressure

(4) Usage:
WICCPH(T)

FUNCTION WICCPC

(1) Description:
Function WICCPC calculates the specific heat at constant pressure for methane as a function of temperature as follows: (Reference 12)

$$c_p = (a + bT + cT^2 + dT^3 + eT^4)R$$

where units are (J/kg-k) for $c_p$, (K) for T, and (J/kg-K) for R. The values of coefficients a, b, c, d, and e are as follows:

$a = 3.82619$
$b = -3.97946 \times 10^{-3}$
$c = 24.5583 \times 10^{-6}$
$d = -22.7329 \times 10^{-9}$
$e = 6.92760 \times 10^{-12}$

(2) Input Variable:
T temperature

(3) Output Variable:
WICCPC specific heat constant pressure

(4) Usage:
WICCPC(T)

## SUBROUTINE NASA

(1) Description:

The subroutine NASA corresponds to MAIN program of NASA-STGSTK program. NASA calls all of the major subroutines in NASA-STGSTK program. NASA first calculates the flow area at inlet and outlet of each stage. It next calls the subroutine CSPREF to calculate reference velocity diagrams at the specified radius for each stage. Then NASA calls CSETA to calculate efficiency if it is not inputed. The pressure coefficient is also calculated by calling CSPI. These computed characteristics for stage can be printed out in this subroutine.

(2) Input Variables:

All input variables are specified in Common blocks.

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL NASA

## SUBROUTINE CSINPT

(1) Description:

The primary purpose of subroutine CSINPT is to read and write the input data which the program requires. For input of design stage performance, there is an option of either of the following input: (i) stage pressure ratio and adiabatic efficiency, or (ii) stage characteristics which consists of pressure coefficient versus flow coefficient and adiabatic efficiency versus flow coefficient. When either of the two above input options are used as input, the input parameters for the option not used are input as zero values. An example of input data is given in Chapter IV.

(2) Input Variables:

All input variables are specified in Common blocks.

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL CSINPT

SUBROUTINE CSPREF

(1) Description:

At design speed and flow, the subroutine CSPREF is coded to calculate: (i) velocity diagram at the specified radius for each stage inlet and outlet, and (ii) selected performance parameter for each stage. Basically CSPREF perform a one-dimensional compressible invicid flow calculation at each rotor inlet and outlet to obtain the velocity diagram for design input conditions.

(2) Input Variables:

All input variables are specified in Common blocks.

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL CSPREF

FUNCTION CPFM

(1) Description:

The subroutine CPFM is used to obtain values of the specific heat at constant pressure, $C_p$, and ratio of specific heats, $\alpha$, as a function of static temperature, t. CPFM calculates the value of the specific heat at constant pressure, $C_p$, from a fifth degree polynomial of static temperature, t, expressed by

$$C_p = \sum_{i=1}^{5} C_i t^i$$

where the polynomial coefficients, $C_i$, are input data read by CSINPT. The value of the ratio of specific heats, $\gamma$, is then

calculated from the following relations:

$\gamma = C_p/(C_p - R)$

where R is gas constant.

(2) Input Variable:

TS — static temperature for which the specific heat at constant pressure is determined

(3) Output Variable:

CPFM — specific heat at constant pressure

(4) Usage:

CPRM(TS)

SUBROUTINE CSETA

(1) Description:

The subroutine CSETA is called by the subroutine NASA when values of stage adiabatic efficiency versus flow coefficient at design speed are not usable input (i.e. values of 0.0 for adiabatic efficiency are inputed). CSETA obtains values of adiabatic efficiency for each stage at the various input flow coefficient for the stage.

(2) Input Variables:

All input variables are specified in Common blocks.

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL CSETA

SUBROUTINE CSPSI

(1) Description:

The subroutine CSPSI is called by the subroutine NASA when values of stage pressure coefficient versus flow coefficient at design speed are not usable input (i.e. input values for stage pressure coefficient equal 0.0). The subroutine CSPSI

obtains values of stage pressure coefficient at the various input flow coefficient for the stage.

(2) Input Variables:

| | |
|---|---|
| XWN | water content |
| LORS | index to specify calculation scheme |
| | LORS=1 for small droplet calculation |
| | LORS=2 for large droplet calculation |

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL CSPSI(XWN, LORS)

SUBROUTINE CSDEVS

(1) Description:

The subroutine CSDEVS calculates the value of stator diffusion constant, K, for small droplet calculation. After determining the value of K, the deviation, $\delta$, can be determined by the following:

$$\delta = \delta^{*} + K\ \{(V_2/V_3) - (V_2/V_3)^{*}\}$$

(2) Input Variables:

| | |
|---|---|
| XW | water content |
| V2M | absolute velocity at stator inlet |
| V3M | absolute velocity at stator outlet |
| V2V3S | ratio of absolute velocity at stator inlet and absolute velocity at stator oulet at the design point |
| I | stage |

(3) Output Variable:

| | |
|---|---|
| FK | diffusion constant |

(4) Usage:

CALL CSDEVS(XW, V2M, V3M, V2V3S, I, FK)

## SUBROUTINE CDEVSL

(1) Description:

The subroutine CDEVSL calculates the value of stator diffusion constant, K, for large droplet calculation. After determining the value of K, the deviation, δ, can be determined by the following:

$$\delta = \delta^* + K\,\{(V_2/V_3) - (V_2/V_3)^*\}$$

(2) Input Variables:

| | |
|---|---|
| XW | water content |
| V2M | absolute velocity at stator inlet |
| V3M | absolute velocity at stator oulet |
| V2V3S | ratio of absolute velocity at stator inlet and absolute velocity at stator oulet at the design point |
| I | stage |

(3) Output Variable:

| | |
|---|---|
| FK | diffusion constant |

(4) Usage:

```
CALL CDEVSL(XW, V2M, V3M, V2V3S, I, FK)
```

## SUBROUTINE CSDEV

(1) Description:

The subroutine CSDEV calculates the value of rotor diffusion angle, K, for small droplet calculation. After determining the value of K, the deviation, δ, can be determined by the following:

$$\delta = \delta^* + K\,\{(W_2/W_3) - (W_2/W_3)^*\}$$

(2) Input Variables:

| | |
|---|---|
| SPEEDF | rotor speed |
| XW | water content |
| V3MR | relative velocity at rotor outlet |
| V2MR | relative velocity at rotor inlet |

| | |
|---|---|
| V3DV2 | ratio of relative velocity at rotor inlet and relative velocity at rotor outlet at the design point |
| I | stage |

(3) Output Variable:

| | |
|---|---|
| FK | diffusion constant |

(4) Usage:

```
CALL CSDEV(SPEEDF, XW, V3MR, V2MR, V3DV2, I, FK)
```

SUBROUTINE CSDEVL

(1) Description:

The subroutine CSDEVL calculates the value of rotor diffusion constant for large droplet calculation. After determining the value of K, the deviation, $\delta$, can be determined by the following:

$$\delta = \delta^* + K \{(W_2/W_3) - (W_2/W_3)^*\}$$

(2) Input Variables:

| | |
|---|---|
| SPEEDF | rotor speed |
| XW | water content |
| V3MR | relative velocity at rotor outlet |
| V2MR | relative velocity at rotor inlet |
| V3DV2 | ratio of relative velocity at rotor inlet and relative velocity at rotor outlet and the design point |
| I | stage |

(3) Output Variable:

| | |
|---|---|
| FK | diffusion constant |

(4) Usage:

```
CALL CSDEVL(SPEED, XW, V3MR, V2MR, V3DV2, I, FK)
```

FUNCTION DELK70

(1) Description:

The function DELK70 calculates the difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 70 per cent rotor speed.

(2) Input Variables:

| | |
|---|---|
| I | stage |
| T1 | $(W_2/W_3) - (W_2/W_3)^*$ |

(3) Output Variable:

| | |
|---|---|
| DELK70 | difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 70 per cent rotor speed |

(4) Usage:

DELK70(I, T1)

FUNCTION DELK80

(1) Description:

The function DELK80 calculates the difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 80 per cent rotor speed.

(2) Input Variables:

| | |
|---|---|
| I | stage |
| T1 | $(W_2/W_3) - (W_2/W_3)^*$ |

(3) Output Variable:

| | |
|---|---|
| DELK80 | difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 80 per cent rotor speed |

(4) Usage:

DELK80(I, T1)

FUNCTION DELK10

(1) Description:

The function DELK10 calculates the difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 100 per cent rotor speed.

(2) Input Variables:

| | |
|---|---|
| I | stage |
| T1 | $(W_2/W_3) - (W_2/W_3)^*$ |

(3) Output Variable:

| | |
|---|---|
| DELK10 | difference between diffusion constant at 90 per cent rotor speed and diffusion constant at 100 per cent rotor speed |

(4) Usage:

DELK10(I, T1)

FUNCTION DPHI

(1) Description:

When the efficiency-flow coefficient curve is input at reference speed, the function DPHI alters the curve for off-reference speed.

(2) Input Variables:

| | |
|---|---|
| I | stage |
| ISPD | rotor speed in per cent |

(3) Output Variable:

| | |
|---|---|
| DPHI | amount of flow coefficient which is shifted for all-reference speed |

(4) Usage:

DPHI(I, ISPD)

SUBROUTINE CSETA1

(1) Description:

The subroutine CSETA1 corrects the stage efficiency for the presence of water in the small droplet calculation.

(2) Input Variables:

| | |
|---|---|
| I | stage |
| J | index for speed |
| K | index for point on a particular speed |
| XW | water content |
| PHID | flow coefficient at design point |
| PHIR | flow coefficient |
| ETAD | stage efficiency before correction for the presence of water |

(3) Output Variable:

| | |
|---|---|
| ETAD | stage efficiency after correction for the presence of water |

(4) Usage:

CALL CSETA1(I, J, K, XW, PHID, PHIR, ETAD)

SUBROUTINE CSETAL

(1) Description:

The subroutine CSETAL corrects the stage efficiency for the presence of water in the large droplet calculation.

(2) Input Variables:

| | |
|---|---|
| I | stage |
| J | index for speed |
| K | index for point on a particular speed |
| XW | water content |
| PHID | flow coefficient at design point |
| PHIR | flow coefficient |
| ETAD | stage efficiency before correction for the presence of water |
| ETADD | stage efficiency at design point |

(3) Output Variable:

| | |
|---|---|
| ETAD | stage efficiency after correction for the presence of water |

(4) Usage:

CALL CSETAL(I, J, K, XW, PHID, PHIR, ETAD, ETADD)

SUBROUTINE CSPSD

(1) Description:

The subroutine CSPSD alters the pressure coefficient for off design speeds. This subroutine is the same as one used in NASA-STGSTK program.

(2) Input Variables:

All input variables are specified in Common blocks.

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL CSPSD

SUBROUTINE CSPAN

(1) Description:

The subroutine CSPAN alters flow coefficient and pressure coefficient for blade reset. This subroutine is the same as one used in NASA-STGSTK program.

(2) Input Variables:

All input variables are specified in Common blocks.

(3) Output Variables:

All output variables are specified in Common blocks.

(4) Usage:

CALL CSPAN

SUBROUTINE CSOUPT

(1) Description:

The subroutine CSOUPT calculates the stage performance and prints them out in the small droplet calculation.

(2) Input Variables:

| | |
|---|---|
| FAIO | initial flow coefficient |
| ISTAGE | stage |
| FLOW1 | mass flow rate |
| ALFA1 | absolute flow angle at rotor inlet |
| BETA1 | relative flow angle at rotor outlet |

(3) Output Variables:

| | |
|---|---|
| BETA2 | relative flow angle at rotor outlet |
| VZ | axial velocity |
| ALFA2 | absolute flow angle at rotor outlet |
| ALFA3 | absolute flow angle at stator outlet |
| DELTG | rise in stagnation temperature of gas phase |
| DELTW | temperature rise of water |
| W1 | relative velocity at rotor inlet |
| W2 | relative velocity at rotor outlet |
| V1 | absolute velocity at stator inlet |
| V2 | absolute velocity at stator outlet |

(4) Usage:

```
CALL CSOUPT(FAIO, ISTAGE, FLOW1, ALFA1, BETA1, BETA2, VZ,
            ALFA2, ALFA3, DELTG, DELTW, W1, W2, V1, V2)
```

SUBROUTINE CSOUPT2

(1) Description:

The subroutine CSOUPT2 calculates the stage performance and prints them out in the small droplet calculation.

(2) Input Variables:

| | |
|---|---|
| FAIO | initial flow coefficient |
| ISTAGE | stage |
| FLOW1 | mass flow rate |
| ALFA1 | absolute flow angle at rotor inlet |
| BETA1 | relative flow angle at rotor outlet |

(3) Output Variables:

| | |
|---|---|
| BETA2 | relative flow angle at rotor outlet |
| VZ | axial velocity |
| ALFA2 | absolute flow angle at rotor outlet |
| ALFA3 | absolute flow angle at stator outlet |
| DELTG | rise in stagnation temperature of gas phase |
| DELTW | temperature rise of water |
| W1 | relative velocity at rotor inlet |
| W2 | relative velocity at rotor outlet |
| V1 | absolute velocity at stator inlet |
| V2 | absolute velocity at stator outlet |

(4) Usage:

```
CALL CSOUPT(FAIO, ISTAGE, FLOW1, ALFA1, BETA1, BETA2, VZ,
           ALFA2, ALFA3, DELTG, DELTW, W1, W2, V1, V2)
```

# APPENDIX 3

## ILLUSTRATIVE TEST CASES FOR THE NASA-WISGSK CODE

Two illustrative test cases for the calculation of the Test Compressor performance utilizing the NASA-WISGSK Code are presented as follows.

1) Test Case No. 1: Operation with air flow at 100 percent of design speed at the meanline section of the compessor.
2) Test Case No. 2: Operation with air-water mixture containing large droplets (with a mass fraction of 0.04 of water) at 100 percent of design speed at the meanline section of the compressor.

Test Case No. 1

****************************** INPUT DATA **************************************

NS(NUMBER OF STAGE)= 6
IPERFM=I
PERFORMANCE AT MEAN

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| RRHUB(I) | .770 | 1.035 | 1.232 | 1.378 | 1.489 | 1.572 | |
| RC(I) | .605 | .554 | .534 | .510 | .483 | .456 | |
| RBLADE(I) | 16.00 | 20.00 | 20.00 | 25.00 | 28.00 | 32.00 | |
| STAGER(I) | 34.25 | 29.96 | 27.37 | 28.30 | 29.17 | 29.75 | |
| STAGES(I) | 23.67 | 25.62 | 26.94 | 28.41 | 29.82 | 38.99 | |
| SRHUB(I) | .923 | 1.145 | 1.311 | 1.445 | 1.538 | 1.580 | .774 |
| SC(I) | .442 | .412 | .412 | .412 | .412 | .412 | |
| SBLADE(I) | 14.00 | 26.00 | 28.00 | 32.00 | 36.00 | 30.00 | |
| SIGUMR(I) | 1.052 | 1.120 | 1.037 | 1.182 | 1.211 | 1.283 | |
| SIGUMS(I) | .640 | 1.061 | 1.093 | 1.199 | 1.311 | 1.087 | |
| FAISTL(I) | I | I | I | I | I | I | |
| GAPR(I) | .125 | .125 | .125 | .125 | .125 | .125 | |
| GAPS(I) | .125 | .125 | .125 | .125 | .125 | .125 | |
| RRTIP(I) | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | |
| SRTIP(I) | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 |
| RT(I) | 2.149 | 2.151 | 2.148 | 2.149 | 2.149 | 2.147 | |
| RM(I) | 1.426 | 1.575 | 1.642 | 1.722 | 1.789 | 1.836 | |
| RH(I) | .781 | 1.056 | 1.252 | 1.411 | 1.533 | 1.621 | |
| SH(I) | 2.147 | 2.136 | 2.127 | 2.123 | 2.118 | 2.100 | |
| SM(I) | 1.502 | 1.573 | 1.637 | 1.712 | 1.766 | 1.784 | |
| SH(I) | .934 | 1.152 | 1.318 | 1.453 | 1.548 | 1.592 | |
| BLOCK(I) | .983 | .976 | .967 | .949 | .923 | .902 | |
| BLOCKS(I) | .978 | .966 | .945 | .928 | .908 | .863 | |
| BET1MR(I) | 42.72 | 42.74 | 41.62 | 42.65 | 44.00 | 45.07 | |
| BET2MR(I) | 25.79 | 17.17 | 13.12 | 13.76 | 14.33 | 14.43 | |
| BET1MS(I) | 35.15 | 40.11 | 43.36 | 45.00 | 46.31 | 48.71 | 0 |
| BET2MS(I) | 12.19 | 11.13 | 10.51 | 11.81 | 13.32 | 29.28 | 21.99 |
| PR12D(I) | 1.154 | 1.165 | 1.221 | 1.237 | 1.230 | 1.215 | |
| PR13D(I) | 1.152 | 1.159 | 1.213 | 1.228 | 1.221 | 1.208 | |
| ETARD(I) | .986 | .986 | .988 | .985 | .982 | .934 | |

```
**************************** INPUT DATA ****************************

FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=    0
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=    0
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=2116.80

DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=  20.0
DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)= 600.0

FND(DESIGN ROTATIONAL SPEED)=51120.0

DSMASS(DESIGN MASS FLOW RATE)=     .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70 R

COMPRESSOR INLET TOTAL PRESSURE=2116.80 LB/FT**2

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

CORRECTED ROTOR SPEED= 51120.0 RPM(  100.0PER CENT OF DESIGN CORRECTED SPEED)
```

```
*************** DESIGN POINT INFORMATION *********** ***

***** COMPRESSOR INLET *****

TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
STATIC PRESSURE AT COMPRESSOR INLET=   1813.73
STATIC DENSITY AT COMPRESSOR INLET=    .06850

ACOUSTIC SPEED AT COMPRESSOR INLET=1092.25914
AXIAL VELOCITY AT COMPRESSOR INLET= 518.81873
MACH NUMBER AT COMPRESSOR INLET=    .47500
STREAMTUBE AREA AT COMPRESSOR INLET=    .01057
FLOW COEFFICIENT AT COMPRESSOR INLET=    .53817
```

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 1 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 518.700 | 2116.800 | 492.637 | 1767.579 | .067 |
| ROTOR OUTLET | 541.148 | 2442.787 | 508.269 | 1931.576 | .072 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 538.76531 | 559.39838 | 725.32398 | 150.52734 | 485.62003 |
| ROTOR OUTLET | 525.97105 | 628.55662 | 618.75550 | 344.14838 | 325.90306 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 636.147 | .514 | .667 | 536.454 | 2381.210 |
| ROTOR OUTLET | 670.051 | .569 | .560 | 540.141 | 5091.790 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 15.61000 | 42.03015 | .01036 | 1.42600 | .55886 |
| ROTOR OUTLET | 33.19714 | 31.78325 | .00937 | 1.50200 | .54559 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15200
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .95383
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15400
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04328

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 2 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 541.148 | 2438.554 | 511.984 | 2008.852 | .074 |
| ROTOR OUTLET | 566.141 | 2840.915 | 522.316 | 2142.394 | .077 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 549.21299 | 591.88727 | 730.68951 | 220.67086 | 481.94532 |
| ROTOR OUTLET | 581.16447 | 725.94045 | 639.44211 | 435.01464 | 266.71034 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 702.617 | .534 | .659 | 556.431 | 2688.136 |
| ROTOR OUTLET | 701.725 | .648 | .571 | 556.331 | 5751.007 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 21.89000 | 41.26765 | .00930 | 1.57500 | .56970 |
| ROTOR OUTLET | 36.81569 | 24.65154 | .00841 | 1.57300 | .60285 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15900
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93231
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.16500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04618

```
*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 3 *****
```

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 566.141 | 2826.284 | 535.362 | 2323.868 | .081 |
| ROTOR OUTLET | 600.462 | 3450.892 | 549.786 | 2533.049 | .086 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 574.81563 | 608.26663 | 784.29006 | 198.93541 | 533.57089 |
| ROTOR OUTLET | 614.43880 | 781.11343 | 662.59507 | 482.28950 | 247.98627 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 732.506 | .536 | .692 | 586.533 | 3199.070 |
| ROTOR OUTLET | 730.276 | .680 | .577 | 586.263 | 6929.751 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 19.09000 | 42.86692 | .00803 | 1.64200 | .59626 |
| ROTOR OUTLET | 38.12932 | 21.97890 | .00708 | 1.63700 | .63736 |

```
STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=      1.21300
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=       .93464
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=      1.22100
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=       .96800
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=     1.06062
```

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 4 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 600.462 | 3428.282 | 569.069 | 2839.988 | .094 |
| ROTOR OUTLET | 639.381 | 4240.785 | 585.841 | 3118.959 | .100 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 580.04590 | 614.69778 | 809.54747 | 203.47020 | 564.72459 |
| ROTOR OUTLET | 619.63965 | 803.61317 | 668.93304 | 511.70446 | 252.02926 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 768.195 | .526 | .692 | 623.519 | 3912.431 |
| ROTOR OUTLET | 763.734 | .678 | .564 | 622.951 | 8231.914 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 19.33000 | 44.23321 | .00692 | 1.72200 | .60169 |
| ROTOR OUTLET | 39.55025 | 22.13332 | .00607 | 1.71200 | .64276 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93002
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23700
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96500
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06481

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 5 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 639.381 | 4209.930 | 606.962 | 3506.755 | .108 |
| ROTOR OUTLET | 679.732 | 5178.214 | 625.197 | 3857.244 | .116 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 586.84149 | 625.22167 | 826.78513 | 215.68308 | 582.40082 |
| ROTOR OUTLET | 617.08868 | 811.58444 | 669.65381 | 527.75042 | 260.07304 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 798.084 | .518 | .685 | 663.653 | 4798.526 |
| ROTOR OUTLET | 787.823 | .663 | .547 | 662.302 | 9691.778 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 20.18000 | 44.76240 | .00591 | 1.78900 | .60873 |
| ROTOR OUTLET | 40.53794 | 22.85308 | .00526 | 1.76600 | .64011 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06311

*************** DESIGN POINT INFORMATION *********** ***

***** STAGE= 6 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 679.732 | 5140.325 | 646.933 | 4318.954 | .125 |
| ROTOR OUTLET | 720.259 | 6245.455 | 665.989 | 4736.291 | .133 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 587.19574 | 629.60666 | 833.74045 | 227.16890 | 591.86199 |
| ROTOR OUTLET | 603.39773 | 811.05676 | 654.61329 | 542.02320 | 253.83017 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 819.051 | .506 | .669 | 704.449 | 5829.034 |
| ROTOR OUTLET | 795.853 | .642 | .518 | 701.350 | 10970.182 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 21.15000 | 45.22772 | .00511 | 1.83600 | .60910 |
| ROTOR OUTLET | 41.93268 | 22.81494 | .00467 | 1.78400 | .62591 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.20800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92365
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .95400
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.05962

*************** DESIGN POINT INFORMATION *********** ***

********** OVERALL PERFORMANCE AT DESIGN POINT ****     ******

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE= 2116.80

CORRECTED MASS FLOW RATE= 3.168

OVERALL TOTAL PRESSURE RATIO=2.9334

OVERALL TOTAL TEMPERATURE RATIO=1.3886

OVERALL ADIABATIC EFFICIENCY= .9223

OVERALL TEMPERATURE RISE= 201.559

| | 1 | 2 | 3 | 4 | 5 | 6 | IGV |
|---|---|---|---|---|---|---|---|
| BET1SR(I) | 42.03 | 41.27 | 42.87 | 44.23 | 44.78 | 45.23 | |
| BET2SR(I) | 31.78 | 24.65 | 21.98 | 22.13 | 22.85 | 22.81 | |
| AINCSR(I) | -.69 | -1.47 | 1.25 | 1.38 | .78 | .16 | |
| ADEVSR(I) | 5.99 | 7.48 | 8.86 | 8.37 | 8.52 | 8.38 | |
| BET1SS(I) | 33.20 | 35.82 | 38.13 | 39.55 | 40.54 | 41.93 | |
| BET2SS(I) | 21.89 | 19.09 | 19.33 | 20.18 | 21.15 | 34.86 | 15.61 |
| AINCSS(I) | -1.95 | -3.29 | -5.23 | -5.45 | -5.77 | -6.78 | |
| ADEVSS(I) | 9.70 | 7.96 | 8.82 | 8.37 | 7.83 | 5.58 | |
| TD(I) | 518.7 | 541.1 | 566.1 | 600.5 | 639.4 | 679.7 | |
| OMEGS(I) | .009 | .021 | .025 | .028 | .029 | .024 | |
| OMEGR(I) | .113 | .018 | .018 | .016 | .004 | .036 | |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 1 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.16675
STAGE TOTAL TEMPERATURE RATIO= 1.04756
STAGE ADIABATIC EFFICIENCY= .94581

STAGE FLOW COEFFICIENT= .501
AXIAL VELOCITY= 480.05
ROTOR SPEED= 958.68

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 2116.8000 | 2469.7801 | 2469.7801 |
| STATIC PRESSURE | 1835.8585 | 2047.8529 | |
| TOTAL TEMPERATURE(GAS) | 518.7000 | 543.3687 | 543.3687 |
| STATIC TEMPERATURE(GAS) | 498.0506 | 515.0967 | |
| STATIC DENSITY(GAS) | .0691 | .0745 | |
| AXIAL VELOCITY | 480.0486 | 467.4542 | |
| ABSOLUTE VELOCITY | 498.4330 | 583.2886 | |
| RELATIVE VELOCITY | 694.6048 | 567.1588 | |
| BLADE SPEED | 636.1474 | 670.0514 | 702.6172 |
| TANG. COMP. OF ABS. VEL. | 134.1223 | 348.8727 | |
| TANG. COMP. OF REL. VEL. | 502.0251 | 321.1787 | |
| ACOUSTIC SPEED | 1093.5459 | 1112.1022 | |
| ABSOLUTE MACH NUMBER | .4558 | .5245 | |
| RELATIVE MACH NUMBER | .6352 | .5100 | |
| FLOW COEFFICIENT | .5007 | .4881 | |
| FLOW AREA | .0104 | .0099 | |
| ABSOLUTE FLOW ANGLE | 15.6100 | 36.7349 | 21.8900 |
| RELATIVE FLOW ANGLE | 46.2819 | 34.4922 | |
| INCIDENCE | 3.5619 | 1.5849 | |
| DEVIATION | | 8.7422 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 1 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.16675
STAGE TOTAL TEMPERATURE RATIO= 1.04756
STAGE ADIABATIC EFFICIENCY= .94773

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | 0 | 0 | 0 |
| XWT= | 0 | 0 | 0 |
| XAIR= | 1.00000 | 1.00000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | 1.00000 | 1.00000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | 0 | 0 | 0 |
| WTMASS= | 0 | 0 | 0 |
| AMASS= | .34491 | .34491 | .34491 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34491 | .34491 | .34491 |
| TMASS= | .34491 | .34491 | .34491 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .07649 | .07444 | .07856 |
| RHOM= | .06904 | .07444 | .07856 |
| RHOG= | .06910 | .07444 | .07856 |
| TG= | 518.70000 | 543.36874 | 543.36874 |
| TW= | 513.70000 | 0 | 0 |
| TWW= | 513.70000 | 0 | 513.70000 |
| P= | 2116.80000 | 2469.78012 | 2469.78012 |
| TB= | 671.40656 | 0 | 679.03308 |
| TDEW= | 271.95506 | 273.23829 | 273.23829 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 2 ) *******************

STAGE TOTAL PRESSURE RATIO= 1.19107
STAGE TOTAL TEMPERATURE RATIO= 1.05518
STAGE ADIABATIC EFFICIENCY= .92667

STAGE FLOW COEFFICIENT= .503
AXIAL VELOCITY= 482.20
ROTOR SPEED= 959.57

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 2469.7801 | 2941.6925 | 2941.6925 |
| STATIC PRESSURE | 2130.2903 | 2311.9417 | |
| TOTAL TEMPERATURE(GAS) | 543.3687 | 573.3511 | 573.3511 |
| STATIC TEMPERATURE(GAS) | 520.9302 | 535.2941 | |
| STATIC DENSITY(GAS) | .0767 | .0810 | |
| AXIAL VELOCITY | 482.2002 | 504.5504 | |
| ABSOLUTE VELOCITY | 519.6676 | 676.8799 | |
| RELATIVE VELOCITY | 701.0474 | 563.3171 | |
| BLADE SPEED | 702.6172 | 701.7250 | 732.5063 |
| TANG. COMP. OF ABS. VEL. | 193.7455 | 451.2154 | |
| TANG. COMP. OF REL. VEL. | 508.8717 | 250.5096 | |
| ACOUSTIC SPEED | 1118.2902 | 1133.6031 | |
| ABSOLUTE MACH NUMBER | .4647 | .5971 | |
| RELATIVE MACH NUMBER | .6269 | .4969 | |
| FLOW COEFFICIENT | .5025 | .5290 | |
| FLOW AREA | .0093 | .0084 | |
| ABSOLUTE FLOW ANGLE | 21.8900 | 41.8060 | 19.0900 |
| RELATIVE FLOW ANGLE | 46.5416 | 26.4044 | |
| INCIDENCE | 3.8016 | 1.6960 | |
| DEVIATION | | 9.2344 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 2 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.19107
STAGE TOTAL TEMPERATURE RATIO= 1.05518
STAGE ADIABATIC EFFICIENCY= .92822

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XU= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | 0 | 0 | 0 |
| XWT= | 0 | 0 | 0 |
| XAIR= | 1.00000 | 1.00000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | 1.00000 | 1.00000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | 0 | 0 | 0 |
| WTMASS= | 0 | 0 | 0 |
| AMASS= | .34491 | .34491 | .34491 |
| CHMASS= | 0 | 0 | 0 |
| UMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34491 | .34491 | .34491 |
| TMASS= | .34491 | .34491 | .34491 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .08519 | .08076 | .09103 |
| RHOM= | .06904 | .08076 | .09103 |
| RHOG= | .07666 | .08076 | .09103 |
| TG= | 543.36874 | 573.35113 | 573.35113 |
| TW= | 0 | 0 | 0 |
| TWW= | 513.70000 | 0 | 513.70000 |
| P= | 2469.78012 | 2941.69246 | 2941.69246 |
| TB= | 679.03308 | 0 | 687.89220 |
| TDEW= | 273.23829 | 274.66167 | 274.66167 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 3 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.23327
STAGE TOTAL TEMPERATURE RATIO= 1.06669
STAGE ADIABATIC EFFICIENCY= .92335

STAGE FLOW COEFFICIENT= .514
AXIAL VELOCITY= 492.32
ROTOR SPEED= 958.24

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 2941.6925 | 3627.8878 | 3627.8878 |
| STATIC PRESSURE | 2555.6014 | 2821.5666 | |
| TOTAL TEMPERATURE(GAS) | 573.3511 | 611.5863 | 611.5863 |
| STATIC TEMPERATURE(GAS) | 550.8154 | 569.3302 | |
| STATIC DENSITY(GAS) | .0870 | .0929 | |
| AXIAL VELOCITY | 492.3213 | 522.1031 | |
| ABSOLUTE VELOCITY | 520.9716 | 713.5891 | |
| RELATIVE VELOCITY | 747.2351 | 576.2383 | |
| BLADE SPEED | 732.5063 | 730.2758 | 768.1948 |
| TANG. COMP. OF ABS. VEL. | 170.3853 | 486.4338 | |
| TANG. COMP. OF REL. VEL. | 562.1210 | 243.8420 | |
| ACOUSTIC SPEED | 1149.6996 | 1168.8627 | |
| ABSOLUTE MACH NUMBER | .4531 | .6105 | |
| RELATIVE MACH NUMBER | .6499 | .4930 | |
| FLOW COEFFICIENT | .5138 | .5502 | |
| FLOW AREA | .0080 | .0071 | |
| ABSOLUTE FLOW ANGLE | 19.0900 | 42.9744 | 19.3300 |
| RELATIVE FLOW ANGLE | 48.7872 | 25.0344 | |
| INCIDENCE | 7.1672 | -.3856 | |
| DEVIATION | | 11.9144 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 3 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.23327
STAGE TOTAL TEMPERATURE RATIO= 1.06669
STAGE ADIABATIC EFFICIENCY= .92441

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XU= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | 0 | 0 | 0 |
| XWT= | 0 | 0 | 0 |
| XAIR= | 1.00000 | 1.00000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | 1.00000 | 1.00000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | 0 | 0 | 0 |
| WTMASS= | 0 | 0 | 0 |
| AMASS= | .34491 | .34491 | .34491 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34491 | .34491 | .34491 |
| TMASS= | .34491 | .34491 | .34491 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .09617 | .09264 | .10713 |
| RHOM= | .06904 | .09264 | .10713 |
| RHOG= | .08698 | .09264 | .10713 |
| TG= | 573.35113 | 611.58634 | 611.58634 |
| TW= | 0 | 0 | 0 |
| TWW= | 513.70000 | 0 | 513.70000 |
| P= | 2941.69246 | 3627.88778 | 3627.88778 |
| TB= | 687.89220 | 0 | 698.82458 |
| TDEW= | 274.66167 | 276.38807 | 276.38807 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 4 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.24777
STAGE TOTAL TEMPERATURE RATIO= 1.07115
STAGE ADIABATIC EFFICIENCY= .91401

STAGE FLOW COEFFICIENT= .512
AXIAL VELOCITY= 491.04
ROTOR SPEED= 958.68

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 3627.8878 | 4526.7581 | 4526.7581 |
| STATIC PRESSURE | 3181.1072 | 3530.5184 | |
| TOTAL TEMPERATURE(GAS) | 611.5863 | 655.1013 | 655.1013 |
| STATIC TEMPERATURE(GAS) | 589.1312 | 610.3937 | |
| STATIC DENSITY(GAS) | .1012 | .1084 | |
| AXIAL VELOCITY | 491.0360 | 521.6561 | |
| ABSOLUTE VELOCITY | 520.3705 | 734.5837 | |
| RELATIVE VELOCITY | 772.1853 | 576.9815 | |
| BLADE SPEED | 768.1948 | 763.7337 | 798.0839 |
| TANG. COMP. OF ABS. VEL. | 172.2471 | 517.1925 | |
| TANG. COMP. OF REL. VEL. | 595.9478 | 246.5412 | |
| ACOUSTIC SPEED | 1188.6369 | 1209.8965 | |
| ABSOLUTE MACH NUMBER | .4378 | .6071 | |
| RELATIVE MACH NUMBER | .6496 | .4769 | |
| FLOW COEFFICIENT | .5122 | .5508 | |
| FLOW AREA | .0069 | .0061 | |
| ABSOLUTE FLOW ANGLE | 19.3300 | 44.7538 | 20.1800 |
| RELATIVE FLOW ANGLE | 50.5129 | 25.2960 | |
| INCIDENCE | 7.6629 | -.2462 | |
| DEVIATION | | 11.5360 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 4 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.24777
STAGE TOTAL TEMPERATURE RATIO= 1.07115
STAGE ADIABATIC EFFICIENCY= .91452

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | 0 | 0 | 0 |
| XWT= | 0 | 0 | 0 |
| XAIR= | 1.00000 | 1.00000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | 1.00000 | 1.00000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | 0 | 0 | 0 |
| WTMASS= | 0 | 0 | 0 |
| AMASS= | .34491 | .34491 | .34491 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34491 | .34491 | .34491 |
| TMASS= | .34491 | .34491 | .34491 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .11118 | .10816 | .12629 |
| RHOM= | .06904 | .10816 | .12629 |
| RHOG= | .10123 | .10816 | .12629 |
| TG= | 611.58634 | 655.10129 | 655.10129 |
| TW= | 0 | 0 | 0 |
| TWW= | 513.70000 | 0 | 513.70000 |
| P= | 3627.68778 | 4526.75812 | 4526.75812 |
| TB= | 698.82458 | 0 | 710.75001 |
| TDEW= | 276.38807 | 278.23445 | 278.23445 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 5 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.24015
STAGE TOTAL TEMPERATURE RATIO= 1.06957
STAGE ADIABATIC EFFICIENCY= .90502

STAGE FLOW COEFFICIENT= .513
AXIAL VELOCITY= 491.33
ROTOR SPEED= 958.68

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 4526.7581 | 5613.8784 | 5613.8784 |
| STATIC PRESSURE | 3998.7709 | 4431.6060 | |
| TOTAL TEMPERATURE(GAS) | 655.1013 | 700.7430 | 700.7430 |
| STATIC TEMPERATURE(GAS) | 632.4225 | 655.2672 | |
| STATIC DENSITY(GAS) | .1185 | .1268 | |
| AXIAL VELOCITY | 491.3271 | 515.3153 | |
| ABSOLUTE VELOCITY | 523.4605 | 741.7059 | |
| RELATIVE VELOCITY | 789.1231 | 574.6752 | |
| BLADE SPEED | 798.0839 | 787.8235 | 819.0509 |
| TANG. COMP. OF ABS. VEL. | 180.5785 | 533.4582 | |
| TANG. COMP. OF REL. VEL. | 617.5054 | 254.3652 | |
| ACOUSTIC SPEED | 1230.9834 | 1253.0193 | |
| ABSOLUTE MACH NUMBER | .4252 | .5919 | |
| RELATIVE MACH NUMBER | .6411 | .4586 | |
| FLOW COEFFICIENT | .5125 | .5454 | |
| FLOW AREA | .0059 | .0053 | |
| ABSOLUTE FLOW ANGLE | 20.1800 | 45.9911 | 21.1500 |
| RELATIVE FLOW ANGLE | 51.4920 | 26.2714 | |
| INCIDENCE | 7.4920 | -.3189 | |
| DEVIATION | | 11.9414 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 5 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.24015
STAGE TOTAL TEMPERATURE RATIO= 1.06967
STAGE ADIABATIC EFFICIENCY= .90499

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUST-MENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUST-MENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | 0 | 0 | 0 |
| XWT= | 0 | 0 | 0 |
| XAIR= | 1.00000 | 1.00000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | 1.00000 | 1.00000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | 0 | 0 | 0 |
| WTMASS= | 0 | 0 | 0 |
| AMASS= | .34491 | .34491 | .34491 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34491 | .34491 | .34491 |
| TMASS= | .34491 | .34491 | .34491 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .12952 | .12654 | .14756 |
| RHOM= | .06904 | .12654 | .14756 |
| RHOG= | .11854 | .12654 | .14756 |
| TG= | 655.10129 | 700.74303 | 700.74303 |
| TW= | 0 | 0 | 0 |
| TWW= | 513.70000 | 0 | 513.70000 |
| P= | 4526.75812 | 5613.87838 | 5613.87838 |
| TB= | 710.75001 | 0 | 725.82464 |
| TDEW= | 278.23445 | 270.76654 | 270.76654 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 6 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.22479
STAGE TOTAL TEMPERATURE RATIO= 1.06583
STAGE ADIABATIC EFFICIENCY= .89836

STAGE FLOW COEFFICIENT= .509
AXIAL VELOCITY= 487.17
ROTOR SPEED= 957.79

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 5613.8784 | 6875.8088 | 6875.8088 |
| STATIC PRESSURE | 5002.4952 | 5515.2479 | |
| TOTAL TEMPERATURE(GAS) | 700.7430 | 746.8730 | 746.8730 |
| STATIC TEMPERATURE(GAS) | 678.2178 | 701.7038 | |
| STATIC DENSITY(GAS) | .1383 | .1473 | |
| AXIAL VELOCITY | 487.1682 | 500.2128 | |
| ABSOLUTE VELOCITY | 522.3545 | 740.2563 | |
| RELATIVE VELOCITY | 796.8461 | 559.2849 | |
| BLADE SPEED | 819.0509 | 795.8534 | .5000 |
| TANG. COMP. OF ABS. VEL. | 188.4712 | 545.6800 | |
| TANG. COMP. OF REL. VEL. | 630.5797 | 250.1734 | |
| ACOUSTIC SPEED | 1274.0547 | 1295.9266 | |
| ABSOLUTE MACH NUMBER | .4100 | .5712 | |
| RELATIVE MACH NUMBER | .6254 | .4316 | |
| FLOW COEFFICIENT | .5086 | .5339 | |
| FLOW AREA | .0051 | .0047 | |
| ABSOLUTE FLOW ANGLE | 21.1500 | 47.4892 | 0 |
| RELATIVE FLOW ANGLE | 52.3113 | 26.5712 | |
| INCIDENCE | 7.2413 | -1.2208 | |
| DEVIATION | | 12.1412 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 6 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.22479
STAGE TOTAL TEMPERATURE RATIO= 1.06583
STAGE ADIABATIC EFFICIENCY= .89787

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | 0 | 0 | 0 |
| XWT= | 0 | 0 | 0 |
| XAIR= | 1.00000 | 1.00000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | 1.00000 | 1.00000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | 0 | 0 | 0 |
| WTMASS= | 0 | 0 | 0 |
| AMASS= | .34491 | .34491 | .34491 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34491 | .34491 | .34491 |
| TMASS= | .34491 | .34491 | .34491 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .15016 | .14714 | .17073 |
| RHOM= | .06904 | .14714 | .17073 |
| RHOG= | .13828 | .14714 | .17073 |
| TG= | 700.74303 | 746.87297 | 746.87297 |
| TW= | 0 | 0 | 0 |
| TWW= | 513.70000 | 0 | 513.70000 |
| P= | 5613.87838 | 6875.80878 | 6875.80878 |
| TB= | 725.82464 | 0 | 738.30219 |
| TDEW= | 270.76654 | 272.48445 | 272.48445 |

```
*********** OVERALL PERFORMANCE **********

 INITIAL FLOW COEFFICIENT=  .50

 CORRECTED SPEED=51120.0     1.000 FRACTION OF DEIGN CORRECTED SPEED

 INITIAL WATER CONTENT(SMALL DROPLET)=    0
 INITIAL WATER CONTENT(LARGE DROPLET)=    0
 INITIAL WATER CONTENT(TOTAL)=    0
 INITIAL RELATIVE HUMIDITY=   .0 PER CENT
 INITIAL METHANE CONTENT=    0

 COMPRESSOR INLET TOTAL TEMPERATURE=  518.70

 COMPRESSOR INLET TOTAL PRESSURE= 2116.80

 CORRECTED MASS FLOW RATE OF MIXTURE=  .345( 2.910)

 CORRECTED MASS FLOW RATE OF GAS PHASE   .345( 2.910)

 OVERALL TOTAL PRESSURE RATIO=3.2482

 OVERALL TOTAL TEMPERATURE RATIO=1.4399

 OVERALL ADIABATIC EFFICIENCY= .9046

 OVERALL TEMPERATURE RISE OF GAS PHASE= 228.173
```

## Test Case No. 2

****************************** INPUT DATA ************************************

NS(NUMBER OF STAGE)= 6
IPERFM=I
PERFORMANCE AT MEAN

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| RRHUB(I) | .770 | 1.035 | 1.232 | 1.378 | 1.489 | 1.572 | |
| RC(I) | .605 | .554 | .534 | .510 | .483 | .456 | |
| RBLADE(I) | 16.00 | 20.00 | 20.00 | 25.00 | 28.00 | 32.00 | |
| STAGER(I) | 34.25 | 29.56 | 27.37 | 28.30 | 29.17 | 29.75 | |
| STAGES(I) | 23.67 | 25.62 | 26.94 | 28.41 | 29.82 | 38.99 | |
| SRHUB(I) | .923 | 1.145 | 1.311 | 1.445 | 1.538 | 1.580 | .774 |
| SC(I) | .442 | .412 | .412 | .412 | .412 | .412 | |
| SBLADE(I) | 14.00 | 26.00 | 28.00 | 32.00 | 36.00 | 30.00 | |
| SIGUMR(I) | 1.052 | 1.120 | 1.037 | 1.182 | 1.211 | 1.283 | |
| SIGUMS(I) | .640 | 1.061 | 1.093 | 1.199 | 1.311 | 1.087 | |
| FAISTL(I) | I | I | I | I | I | I | |
| GAPR(I) | .125 | .125 | .125 | .125 | .125 | .125 | |
| GAPS(I) | .125 | .125 | .125 | .125 | .125 | .125 | |
| RRTIP(I) | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | |
| SRTIP(I) | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 | 2.16 |
| RT(I) | 2.149 | 2.151 | 2.148 | 2.149 | 2.149 | 2.147 | |
| RM(I) | 1.426 | 1.575 | 1.642 | 1.722 | 1.789 | 1.836 | |
| RH(I) | .781 | 1.056 | 1.252 | 1.411 | 1.533 | 1.621 | |
| SH(I) | 2.147 | 2.138 | 2.127 | 2.123 | 2.118 | 2.100 | |
| SM(I) | 1.502 | 1.573 | 1.637 | 1.712 | 1.766 | 1.784 | |
| SH(I) | .934 | 1.152 | 1.318 | 1.453 | 1.548 | 1.592 | |
| BLOCK(I) | .983 | .976 | .967 | .949 | .923 | .902 | |
| BLOCKS(I) | .978 | .966 | .945 | .928 | .908 | .863 | |
| BET1MR(I) | 42.72 | 42.74 | 41.62 | 42.85 | 44.00 | 45.07 | |
| BET2MR(I) | 25.79 | 17.17 | 13.12 | 13.76 | 14.33 | 14.43 | |
| BET1MS(I) | 35.15 | 40.11 | 43.36 | 45.00 | 46.31 | 48.71 | 0 |
| BET2MS(I) | 12.19 | 11.13 | 10.51 | 11.81 | 13.32 | 29.28 | 21.99 |
| PR12D(I) | 1.154 | 1.165 | 1.221 | 1.237 | 1.230 | 1.215 | |
| PR13D(I) | 1.152 | 1.159 | 1.213 | 1.226 | 1.221 | 1.208 | |
| ETARD(I) | .966 | .966 | .968 | .965 | .962 | .954 | |

```
****************************** INPUT DATA ******************************

FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=    0
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)= .040
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=2116.80

DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=  20.0
DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)= 600.0

FND(DESIGN ROTATIONAL SPEED)=51120.0

DSMASS(DESIGN MASS FLOW RATE)=     .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70 R

COMPRESSOR INLET TOTAL PRESSURE=2116.80 LB/FT**2

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

CORRECTED ROTOR SPEED= 51120.0 RPM(  100.0PER CENT OF DESIGN CORRECTED SPEED)
```

```
*************** DESIGN POINT INFORMATION ************ ***

 ***** COMPRESSOR INLET *****

 TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
 TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
 STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
 STATIC PRESSURE AT COMPRESSOR INLET=   1813.73
 STATIC DENSITY AT COMPRESSOR INLET=    .06850

 ACOUSTIC SPEED AT COMPRESSOR INLET=1092.25914
 AXIAL VELOCITY AT COMPRESSOR INLET= 518.81873
 MACH NUMBER AT COMPRESSOR INLET=    .47500
 STREAMTUBE AREA AT COMPRESSOR INLET=    .01057
 FLOW COEFFICIENT AT COMPRESSOR INLET=    .53817
```

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 1 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 518.700 | 2116.800 | 492.637 | 1767.579 | .067 |
| ROTOR OUTLET | 541.148 | 2442.787 | 508.269 | 1961.576 | .072 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 538.76531 | 559.39838 | 725.32398 | 150.52734 | 485.62003 |
| ROTOR OUTLET | 525.97105 | 628.55682 | 618.75550 | 344.14838 | 325.90306 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 636.147 | .514 | .667 | 536.454 | 2381.210 |
| ROTOR OUTLET | 670.051 | .569 | .560 | 540.141 | 5091.790 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 15.61000 | 42.03015 | .01036 | 1.42600 | .55886 |
| ROTOR OUTLET | 33.19714 | 31.78325 | .00987 | 1.50200 | .54559 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15200
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .95383
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15400
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04328

*************** DESIGN POINT INFORMATION *********** ***

***** STAGE= 2 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 541.148 | 2438.554 | 511.984 | 2008.852 | .074 |
| ROTOR OUTLET | 566.141 | 2840.915 | 522.316 | 2142.394 | .077 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 549.21299 | 591.88727 | 730.68951 | 220.67086 | 481.94632 |
| ROTOR OUTLET | 581.16447 | 725.94045 | 639.44211 | 435.01464 | 266.71034 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 702.617 | .534 | .659 | 556.431 | 2688.136 |
| ROTOR OUTLET | 701.725 | .648 | .571 | 556.331 | 5751.007 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 21.89000 | 41.26765 | .00930 | 1.57500 | .56970 |
| ROTOR OUTLET | 36.81569 | 24.65154 | .00841 | 1.57300 | .60285 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15900
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93231
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.16500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04618

*************** DESIGN POINT INFORMATION *********** ***

***** STAGE= 3 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 566.141 | 2826.224 | 535.362 | 2323.868 | .081 |
| ROTOR OUTLET | 600.462 | 3450.892 | 549.786 | 2533.049 | .086 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 574.81563 | 608.26663 | 784.29006 | 198.93541 | 533.57089 |
| ROTOR OUTLET | 614.43880 | 781.11343 | 662.59507 | 482.28950 | 247.98627 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 732.506 | .536 | .692 | 586.533 | 3199.070 |
| ROTOR OUTLET | 730.276 | .680 | .577 | 586.263 | 6929.751 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 19.09000 | 42.86892 | .00803 | 1.64200 | .59626 |
| ROTOR OUTLET | 38.12932 | 21.97690 | .00708 | 1.63700 | .63736 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21300
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93464
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96800
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06062

*************** DESIGN POINT INFORMATION *********** ***

***** STAGE= 4 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 600.462 | 3428.282 | 569.069 | 2839.938 | .094 |
| ROTOR OUTLET | 639.381 | 4240.785 | 585.841 | 3118.959 | .100 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 580.04590 | 614.69778 | 809.54747 | 203.47020 | 564.72459 |
| ROTOR OUTLET | 619.63965 | 803.61317 | 668.93304 | 511.70446 | 252.02926 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 768.195 | .526 | .692 | 623.519 | 3912.431 |
| ROTOR OUTLET | 763.734 | .678 | .564 | 622.951 | 8231.914 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 19.33000 | 44.23321 | .00692 | 1.72200 | .60169 |
| ROTOR OUTLET | 39.55025 | 22.13332 | .00607 | 1.71200 | .64276 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93002
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23700
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96500
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06431

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 5 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 639.381 | 4209.930 | 606.962 | 3506.755 | .108 |
| ROTOR OUTLET | 679.732 | 5178.214 | 625.197 | 3857.244 | .116 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 586.84149 | 625.22167 | 826.78513 | 215.68308 | 582.40082 |
| ROTOR OUTLET | 617.08868 | 811.58444 | 669.65381 | 527.75042 | 260.07304 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 798.084 | .518 | .685 | 663.653 | 4798.526 |
| ROTOR OUTLET | 787.823 | .663 | .547 | 662.302 | 9691.778 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 20.18000 | 44.78240 | .00591 | 1.78900 | .60873 |
| ROTOR OUTLET | 40.53794 | 22.65308 | .00526 | 1.76600 | .64011 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06311

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 6 *****

| | TOTAL TEMP | TOTAL PRESSURE | STATIC TEMP | STATIC PRESSURE | STATIC DENSITY |
|---|---|---|---|---|---|
| ROTOR INLET | 679.732 | 5140.325 | 646.933 | 4318.954 | .125 |
| ROTOR OUTLET | 720.259 | 6245.495 | 665.989 | 4736.291 | .133 |

| | AXIAL VELOCITY | ABSOLUTE VELOCITY | RELATIVE VELOCITY | TAN COMP OF ABS VEL | TAN COMP OF REL VEL |
|---|---|---|---|---|---|
| ROTOR INLET | 587.19574 | 629.60666 | 833.74045 | 227.16890 | 591.88199 |
| ROTOR OUTLET | 603.39773 | 811.09676 | 654.61329 | 542.02320 | 253.83017 |

| | ROTOR SPEED | ABS MACH NUMBER | REL MACH NUMBER | REL TOTAL TEMP | REL TOTAL PRESSURE |
|---|---|---|---|---|---|
| ROTOR INLET | 819.051 | .506 | .669 | 704.449 | 5829.034 |
| ROTOR OUTLET | 795.853 | .642 | .518 | 701.350 | 10970.182 |

| | ABS FLOW ANGLE | REL FLOW ANGLE | STREAMTUBE AREA | RADIUS | FLOW COEFFICIENT |
|---|---|---|---|---|---|
| ROTOR INLET | 21.15000 | 45.22772 | .00511 | 1.83600 | .60910 |
| ROTOR OUTLET | 41.93288 | 22.81494 | .00467 | 1.78400 | .62591 |

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.20800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92365
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .95400
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.05962

*************** DESIGN POINT INFORMATION ************ ***

********** OVERALL PERFORMANCE AT DESIGN POINT **** ******

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE= 2116.80

CORRECTED MASS FLOW RATE= 3.168

OVERALL TOTAL PRESSURE RATIO=2.9334

OVERALL TOTAL TEMPERATURE RATIO=1.3886

OVERALL ADIABATIC EFFICIENCY= .9223

OVERALL TEMPERATURE RISE= 201.559

| | 1 | 2 | 3 | 4 | 5 | 6 | IGV |
|---|---|---|---|---|---|---|---|
| BET1SR(I) | 42.03 | 41.27 | 42.87 | 44.23 | 44.78 | 45.23 | |
| BET2SR(I) | 31.78 | 24.65 | 21.98 | 22.13 | 22.85 | 22.81 | |
| AINCSR(I) | -.69 | -1.47 | 1.25 | 1.38 | .78 | .16 | |
| ADEVSR(I) | 5.99 | 7.48 | 8.86 | 8.37 | 8.52 | 8.38 | |
| BET1SS(I) | 33.20 | 36.82 | 38.13 | 39.55 | 40.54 | 41.93 | |
| BET2SS(I) | 21.89 | 19.09 | 19.33 | 20.18 | 21.15 | 34.86 | 15.61 |
| AINCSS(I) | -1.95 | -3.29 | -5.23 | -5.45 | -5.77 | -6.78 | |
| ADEVSS(I) | 9.70 | 7.96 | 8.82 | 8.37 | 7.83 | 5.58 | |
| TD(I) | 518.7 | 541.1 | 566.1 | 600.5 | 639.4 | 679.7 | |
| OMEGS(I) | .009 | .021 | .025 | .028 | .029 | .024 | |
| OMEGR(I) | .113 | .018 | .018 | .016 | .004 | .036 | |

```
*******************   INITIAL FLOW COEFFICIENT=  .500 (STAGE= 1 )  *****************

    STAGE TOTAL PRESSURE RATIO=      1.15672
    STAGE TOTAL TEMPERATURE RATIO=     1.04806
    STAGE ADIABATIC EFFICIENCY=      .88250

    STAGE FLOW COEFFICIENT= .498
    AXIAL VELOCITY= 477.45
    ROTOR SPEED= 958.68
```

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 2116.8000 | 2448.5450 | 2448.5450 |
| STATIC PRESSURE | 1838.7412 | 2026.0491 | |
| TOTAL TEMPERATURE(GAS) | 518.7000 | 543.6271 | 543.6271 |
| STATIC TEMPERATURE(GAS) | 498.2736 | 515.0376 | |
| STATIC DENSITY(GAS) | .0692 | .0737 | |
| AXIAL VELOCITY | 477.4496 | 470.3117 | |
| ABSOLUTE VELOCITY | 495.7345 | 586.5545 | |
| RELATIVE VELOCITY | 693.3375 | 568.5979 | |
| BLADE SPEED | 636.1474 | 670.0514 | 702.6172 |
| TANG. COMP. OF ABS. VEL. | 133.3962 | 350.5041 | |
| TANG. COMP. OF REL. VEL. | 502.7512 | 319.5474 | |
| ACOUSTIC SPEED | 1093.7509 | 1112.0385 | |
| ABSOLUTE MACH NUMBER | .4532 | .5275 | |
| RELATIVE MACH NUMBER | .6339 | .5113 | |
| FLOW COEFFICIENT | .4980 | .4910 | |
| FLOW AREA | .0104 | .0099 | |
| ABSOLUTE FLOW ANGLE | 15.6100 | 36.6957 | 21.8900 |
| RELATIVE FLOW ANGLE | 46.4786 | 34.1937 | |
| INCIDENCE | 3.7586 | 1.5457 | |
| DEVIATION | | 8.4437 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 1 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.15672
STAGE TOTAL TEMPERATURE RATIO= 1.04806
STAGE ADIABATIC EFFICIENCY= .88429

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | .04000 | .04000 | .04000 |
| XWT= | .04000 | .04000 | .04000 |
| XAIR= | .96000 | .96000 | .96000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | .96000 | .96000 | .96000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | .01431 | .01431 | .01431 |
| WTMASS= | .01431 | .01431 | .01431 |
| AMASS= | .34340 | .34340 | .34340 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34340 | .34340 | .34340 |
| TMASS= | .35771 | .35771 | .35771 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .07649 | .07304 | .07106 |
| RHOM= | .07160 | .07608 | .08067 |
| RHOG= | .06918 | .07304 | .07745 |
| TG= | 518.70000 | 543.62714 | 543.62714 |
| TW= | 513.70000 | 0 | 513.70000 |
| TWW= | 513.70000 | 0 | 513.70001 |
| P= | 2116.80000 | 2448.54498 | 2448.54498 |
| TB= | 671.40656 | 0 | 678.60149 |
| TDEW= | 271.99506 | 273.16838 | 307.24761 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 2 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.17978
STAGE TOTAL TEMPERATURE RATIO= 1.05521
STAGE ADIABATIC EFFICIENCY= .87441

STAGE FLOW COEFFICIENT= .505
AXIAL VELOCITY= 485.01
ROTOR SPEED= 959.57

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 2448.5450 | 2828.7433 | 2888.7433 |
| STATIC PRESSURE | 2108.3989 | 2257.6036 | |
| TOTAL TEMPERATURE(GAS) | 543.6271 | 573.6432 | 573.6432 |
| STATIC TEMPERATURE(GAS) | 520.9261 | 534.7088 | |
| STATIC DENSITY(GAS) | .0759 | .0792 | |
| AXIAL VELOCITY | 485.0120 | 513.6592 | |
| ABSOLUTE VELOCITY | 522.6978 | 684.6335 | |
| RELATIVE VELOCITY | 702.1670 | 570.8697 | |
| BLADE SPEED | 702.6172 | 701.7250 | 732.5063 |
| TANG. COMP. OF ABS. VEL. | 194.8752 | 452.6337 | |
| TANG. COMP. OF REL. VEL. | 507.7420 | 249.0912 | |
| ACOUSTIC SPEED | 1118.2885 | 1132.9858 | |
| ABSOLUTE MACH NUMBER | .4674 | .6043 | |
| RELATIVE MACH NUMBER | .6279 | .5039 | |
| FLOW COEFFICIENT | .5054 | .5386 | |
| FLOW AREA | .0093 | .0084 | |
| ABSOLUTE FLOW ANGLE | 21.8900 | 41.3863 | 19.0900 |
| RELATIVE FLOW ANGLE | 46.3116 | 25.8704 | |
| INCIDENCE | 3.5716 | 1.2763 | |
| DEVIATION | | 8.7004 | |

******************* INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 2 ) *******************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.17978
STAGE TOTAL TEMPERATURE RATIO= 1.05521
STAGE ADIABATIC EFFICIENCY= .87586

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | .04000 | .04000 | .04000 |
| XWT= | .04000 | .04000 | .04000 |
| XAIR= | .96000 | .96000 | .96000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | .96000 | .96000 | .96000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | .01431 | .01431 | .01431 |
| WTMASS= | .01431 | .01431 | .01431 |
| AMASS= | .34340 | .34340 | .34340 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34340 | .34340 | .34340 |
| TMASS= | .35771 | .35771 | .35771 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .08442 | .07792 | .08381 |
| RHOM= | .07160 | .08116 | .09264 |
| RHOG= | .07588 | .07792 | .08894 |
| TG= | 543.62714 | 573.64319 | 573.64319 |
| TW= | 513.70000 | 0 | 513.70000 |
| TWW= | 513.70001 | 0 | 513.70002 |
| P= | 2448.54498 | 2888.74326 | 2888.74326 |
| TB= | 678.60149 | 0 | 686.96120 |
| TDEW= | 307.24761 | 308.94985 | 321.39871 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 3 ) *******************

STAGE TOTAL PRESSURE RATIO= 1.22015
STAGE TOTAL TEMPERATURE RATIO= 1.06595
STAGE ADIABATIC EFFICIENCY= .86472

STAGE FLOW COEFFICIENT= .523
AXIAL VELOCITY= 501.06
ROTOR SPEED= 958.24

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 2888.7433 | 3524.7140 | 3524.7140 |
| STATIC PRESSURE | 2496.9126 | 2718.3592 | |
| TOTAL TEMPERATURE(GAS) | 573.6432 | 611.4751 | 611.4751 |
| STATIC TEMPERATURE(GAS) | 550.3001 | 567.8626 | |
| STATIC DENSITY(GAS) | .0851 | .0897 | |
| AXIAL VELOCITY | 501.0593 | 537.7831 | |
| ABSOLUTE VELOCITY | 530.2182 | 724.9365 | |
| RELATIVE VELOCITY | 750.7661 | 590.6081 | |
| BLADE SPEED | 732.5063 | 730.2758 | 768.1948 |
| TANG. COMP. OF ABS. VEL. | 173.4094 | 486.1298 | |
| TANG. COMP. OF REL. VEL. | 559.0969 | 244.1460 | |
| ACOUSTIC SPEED | 1149.1717 | 1167.3652 | |
| ABSOLUTE MACH NUMBER | .4614 | .6210 | |
| RELATIVE MACH NUMBER | .6533 | .5059 | |
| FLOW COEFFICIENT | .5229 | .5668 | |
| FLOW AREA | .0080 | .0071 | |
| ABSOLUTE FLOW ANGLE | 19.0900 | 42.1120 | 19.3300 |
| RELATIVE FLOW ANGLE | 48.1335 | 24.4174 | |
| INCIDENCE | 6.5135 | -1.2480 | |
| DEVIATION | | 11.2974 | |

******************* INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 3 ) *******************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.22015
STAGE TOTAL TEMPERATURE RATIO= 1.06595
STAGE ADIABATIC EFFICIENCY= .88573

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | .04000 | .04000 | .04000 |
| XWT= | .04000 | .04000 | .04000 |
| XAIR= | .96000 | .96000 | .96000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | .96000 | .96000 | .96000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | .01431 | .01431 | .01431 |
| WTMASS= | .01431 | .01431 | .01431 |
| AMASS= | .34340 | .34340 | .34340 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34340 | .34340 | .34340 |
| TMASS= | .35771 | .35771 | .35771 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .09439 | .08818 | .09954 |
| RHOM= | .07160 | .09185 | .10802 |
| RHOG= | .08506 | .08818 | .10370 |
| TG= | 573.64319 | 611.47514 | 611.47514 |
| TW= | 513.70000 | 0 | 513.70000 |
| TWW= | 513.70002 | 0 | 513.70004 |
| P= | 2888.74326 | 3524.71402 | 3524.71402 |
| TB= | 686.96120 | 0 | 697.29964 |
| TDEW= | 321.39871 | 323.64370 | 332.71852 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 4 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.24003
STAGE TOTAL TEMPERATURE RATIO= 1.06975
STAGE ADIABATIC EFFICIENCY= .90548

STAGE FLOW COEFFICIENT= .528
AXIAL VELOCITY= 505.84
ROTOR SPEED= 958.68

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 3524.7140 | 4370.7663 | 4370.7663 |
| STATIC PRESSURE | 3065.3014 | 3378.4066 | |
| TOTAL TEMPERATURE(GAS) | 611.4751 | 654.1230 | 654.1230 |
| STATIC TEMPERATURE(GAS) | 587.6443 | 607.9245 | |
| STATIC DENSITY(GAS) | .0978 | .1042 | |
| | | | |
| AXIAL VELOCITY | 505.8407 | 540.1630 | |
| ABSOLUTE VELOCITY | 536.0596 | 746.6944 | |
| RELATIVE VELOCITY | 777.7311 | 594.4566 | |
| BLADE SPEED | 768.1948 | 763.7337 | 793.0839 |
| TANG. COMP. OF ABS. VEL. | 177.4403 | 515.5351 | |
| TANG. COMP. OF REL. VEL. | 590.7545 | 248.1986 | |
| ACOUSTIC SPEED | 1187.1599 | 1207.4712 | |
| ABSOLUTE MACH NUMBER | .4515 | .6184 | |
| RELATIVE MACH NUMBER | .6551 | .4923 | |
| | | | |
| FLOW COEFFICIENT | .5276 | .5703 | |
| FLOW AREA | .0069 | .0061 | |
| | | | |
| ABSOLUTE FLOW ANGLE | 19.3300 | 43.6636 | 20.1800 |
| RELATIVE FLOW ANGLE | 49.4278 | 24.6782 | |
| INCIDENCE | 6.5778 | -1.3364 | |
| DEVIATION | | 10.9182 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 4 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.24003
STAGE TOTAL TEMPERATURE RATIO= 1.06975
STAGE ADIABATIC EFFICIENCY= .90596

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUST-MENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUST-MENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | .04000 | .04000 | .04000 |
| XWT= | .04000 | .04000 | .04000 |
| XAIR= | .96000 | .96000 | .96000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | .96000 | .96000 | .96000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | .01431 | .01431 | .01431 |
| WTMASS= | .01431 | .01431 | .01431 |
| AMASS= | .34340 | .34340 | .34340 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34340 | .34340 | .34340 |
| TMASS= | .35771 | .35771 | .35771 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .10804 | .10243 | .11841 |
| RHOM= | .07160 | .10669 | .12684 |
| RHOG= | .09779 | .10243 | .12178 |
| TG= | 611.47514 | 654.12304 | 654.12303 |
| TW= | 513.70000 | 0 | 513.70000 |
| TWW= | 513.70004 | 0 | 513.70008 |
| P= | 3524.71402 | 4370.76630 | 4370.76630 |
| TB= | 697.29364 | 0 | 708.83369 |
| TDEW= | 332.71852 | 335.32202 | 342.89517 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 5 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.23254
STAGE TOTAL TEMPERATURE RATIO= 1.06806
STAGE ADIABATIC EFFICIENCY= .89928

STAGE FLOW COEFFICIENT= .531
AXIAL VELOCITY= 509.08
ROTOR SPEED= 958.68

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 4370.7663 | 5387.1456 | 5387.1456 |
| STATIC PRESSURE | 3624.4632 | 4211.8618 | |
| TOTAL TEMPERATURE(GAS) | 654.1230 | 698.6417 | 698.6417 |
| STATIC TEMPERATURE(GAS) | 629.7729 | 651.5103 | |
| STATIC DENSITY(GAS) | .1138 | .1212 | |
| AXIAL VELOCITY | 509.0775 | 536.3520 | |
| ABSOLUTE VELOCITY | 542.3718 | 755.0109 | |
| RELATIVE VELOCITY | 795.2725 | 594.5041 | |
| BLADE SPEED | 798.0839 | 787.8235 | 819.0509 |
| TANG. COMP. OF ABS. VEL. | 187.1023 | 531.3831 | |
| TANG. COMP. OF REL. VEL. | 610.9816 | 256.4404 | |
| ACOUSTIC SPEED | 1228.4506 | 1249.4716 | |
| ABSOLUTE MACH NUMBER | .4415 | .6043 | |
| RELATIVE MACH NUMBER | .6474 | .4758 | |
| FLOW COEFFICIENT | .5310 | .5677 | |
| FLOW AREA | .0059 | .0053 | |
| ABSOLUTE FLOW ANGLE | 20.1800 | 44.7334 | 21.1500 |
| RELATIVE FLOW ANGLE | 50.1965 | 25.5534 | |
| INCIDENCE | 6.1965 | -1.5766 | |
| DEVIATION | | 11.2234 | |

******************** INITIAL FLOW COEFFICIENT= .500 (ISTAGE= 5 ) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.23254
STAGE TOTAL TEMPERATURE RATIO= 1.06806
STAGE ADIABATIC EFFICIENCY= .89922

| | **STAGE INLET** | **STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT) | **STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT) |
|---|---|---|---|
| XV= | .00000 | .00000 | .00000 |
| XW= | 0 | 0 | 0 |
| XWW= | .04000 | .04000 | 0 |
| XWT= | .04000 | .04000 | 0 |
| XAIR= | .96000 | .96000 | 1.00000 |
| XMETAN= | 0 | 0 | 0 |
| XGAS | .96000 | .96000 | 1.00000 |
| WMASS= | 0 | 0 | 0 |
| WWMASS= | .01431 | .01431 | 0 |
| WTMASS= | .01431 | .01431 | 0 |
| AMASS= | .34342 | .34342 | .34342 |
| CHMASS= | 0 | 0 | 0 |
| VMASS= | .00000 | .00000 | .00000 |
| GMASS= | .34340 | .34340 | .34342 |
| TMASS= | .35771 | .35771 | .34342 |
| WS= | .00000 | .00000 | .00000 |
| RHOA= | .12524 | .11937 | .14183 |
| RHOM= | .07160 | .12434 | .14183 |
| RHOG= | .11385 | .11937 | .14183 |
| TG= | 654.12303 | 698.64174 | 698.64174 |
| TW= | 513.70000 | 0 | 0 |
| TWW= | 513.70008 | 0 | 513.70008 |
| P= | 4370.76630 | 5387.14558 | 5387.14558 |
| TB= | 708.83369 | 0 | 723.33915 |
| TDEW= | 342.69517 | 335.97580 | 335.97580 |

******************** INITIAL FLOW COEFFICIENT= .500 (STAGE= 6 ) ******************

STAGE TOTAL PRESSURE RATIO= 1.22195
STAGE TOTAL TEMPERATURE RATIO= 1.06404
STAGE ADIABATIC EFFICIENCY= .91275

STAGE FLOW COEFFICIENT= .530
AXIAL VELOCITY= 507.49
ROTOR SPEED= 957.79

| | *ROTOR INLET* | *ROTOR OUTLET* | *STATOR OUTLET* |
|---|---|---|---|
| TOTAL PRESSURE | 5387.1456 | 6582.8080 | 6582.8080 |
| STATIC PRESSURE | 4750.8882 | 5234.7740 | |
| TOTAL TEMPERATURE(GAS) | 698.6417 | 743.3858 | 743.3858 |
| STATIC TEMPERATURE(GAS) | 674.1926 | 696.7068 | |
| STATIC DENSITY(GAS) | .1321 | .1409 | |
| AXIAL VELOCITY | 507.4865 | 520.7245 | |
| ABSOLUTE VELOCITY | 544.1403 | 752.4057 | |
| RELATIVE VELOCITY | 803.3192 | 578.8237 | |
| BLADE SPEED | 819.0509 | 795.8534 | .5000 |
| TANG. COMP. OF ABS. VEL. | 196.3317 | 543.1026 | |
| TANG. COMP. OF REL. VEL. | 622.7192 | 252.7508 | |
| ACOUSTIC SPEED | 1270.3492 | 1291.3863 | |
| ABSOLUTE MACH NUMBER | .4283 | .5826 | |
| RELATIVE MACH NUMBER | .6324 | .4482 | |
| FLOW COEFFICIENT | .5299 | .5558 | |
| FLOW AREA | .0051 | .0047 | |
| ABSOLUTE FLOW ANGLE | 21.1500 | 46.2051 | 0 |
| RELATIVE FLOW ANGLE | 50.8216 | 25.8911 | |
| INCIDENCE | 5.7516 | -2.5049 | |
| DEVIATION | | 11.4611 | |

```
******************    INITIAL FLOW COEFFICIENT=  .500 (ISTAGE=  6 )  ******************

    STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

    STAGE TOTAL PRESSURE RATIO=       1.22195
    STAGE TOTAL TEMPERATURE RATIO=      1.06404
    STAGE ADIABATIC EFFICIENCY=       .91223

           **STAGE INLET**      **STAGE OUTLET**      **STAGE OUTLET**
                                 (BEFORE INTER-        (AFTER INTER-
                                 STAGE ADJUST-         STAGE ADJUST-
                                 MENT)                 MENT)
    XV=          .00000              .00000              .00000
    XW=               0                   0                   0
    XWW=              0                   0                   0
    XWT=              0                   0                   0
    XAIR=       1.00000             1.00000             1.00000
    XMETAN=           0                   0                   0
    XGAS        1.00000             1.00000             1.00000
    WMASS=            0                   0                   0
    WWMASS=           0                   0                   0
    WTMASS=           0                   0                   0
    AMASS=       .34342              .34342              .34342
    CHMASS=           0                   0                   0
    VMASS=       .00000              .00000              .00000
    GMASS=       .34342              .34342              .34342
    TMASS=       .34342              .34342              .34342
    WS=          .00000              .00000              .00000
    RHOA=        .14453              .14061              .16408
    RHOM=        .07160              .14061              .16408
    RHOG=        .13211              .14061              .16408
    TG=       698.64174           743.38580           743.38580
    TW=               0                   0                   0
    TWW=      513.70008                   0           513.70008
    P=       5387.14558          6582.80801          6582.80801
    TB=       723.33915                   0           735.58638
    TDEW=     335.97580           338.59428           338.59428
```

```
********** OVERALL PERFORMANCE *********

 INITIAL FLOW COEFFICIENT=  .50

 CORRECTED SPEED=51120.0      1.000 FRACTION OF DEIGN CORRECTED SPEED

 INITIAL WATER CONTENT(SMALL DROPLET)=    0
 INITIAL WATER CONTENT(LARGE DROPLET)= .040
 INITIAL WATER CONTENT(TOTAL)= .040
 INITIAL RELATIVE HUMIDITY=   .0 PER CENT
 INITIAL METHANE CONTENT=    0

 COMPRESSOR INLET TOTAL TEMPERATURE=  518.70

 COMPRESSOR INLET TOTAL PRESSURE= 2116.80

 CORRECTED MASS FLOW RATE OF MIXTURE=  .358( 3.018)

 CORRECTED MASS FLOW RATE OF GAS PHASE   .343( 2.897)

 OVERALL TOTAL PRESSURE RATIO=3.1058

 OVERALL TOTAL TEMPERATURE RATIO=1.4332

 OVERALL ADIABATIC EFFICIENCY= .8790

 OVERALL TEMPERATURE RISE OF GAS PHASE= 224.686
```

## APPENDIX 4

## PROGRAM SOURCE LIST

```
C
      PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C PROGRAM NASA-WISGSK
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C ABSTRACT:
C THIS PROGRAM CODE HAS BEEN PRODUCED FOR THE STUDY OF THE AXIAL FLOW
C COMPRESSOR PERFORMANCE FOR THE GAS-WATER DROPLET MIXTURE FLOW.
C THE MIXTURE CONSISTS  OF TWO TYPES OF DROPLET SIZES AND THREE
C KINDS OF GASEOUS PHASES.THIS PROGRAM CODE IS WRITTEN ESPECIALLY
C FOR AIR+WATER VAPOR+METHANE+SMALL DROPLET+LARGE DROPLET.
C THIS FORTRAN COMPUTER CODE CAN PREDICT THE DESIGN AND OFF-DESIGN
C PERFORMANCE OF AXIAL FLOW COMPRESSOR.  STAGE AND OVERALL PERFORMANCE
C ARE OBTAINED BY A STAGE-BY-STAGE CALCULATION.
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      REAL ND,NU,KA,M,MMASS,MMASS1
      REAL MMASSO
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
     X, UTIPG(6),UTIP(6),UTIPD(6),UCU(6),UMEAN(6),UHUB(6),U(6),FAI
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8),
     * PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)
     *,PSI4(12,2,8),PSI5(12,2,8)
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
     X,XAR,XMET,XSTM
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE
      DIMENSION D(20,3) , XD(20,3) , XXD(20,3),
     ,WS(3),WMASS(3),VMASS(3),RHOA(3),RHOM(3),TB(3)
      DIMENSION TD(6),DELZ(6),ETAA(6)
      DIMENSION XXA(3),XXV(3),DAVE(20)
      DIMENSION TDEW(3)
      DIMENSION DDAVE(20),WWMASS(3),WTMASS(3)
      DIMENSION TMASS(3),GMASS(3),XAIR(3),XMETAN(3),XGAS(3),FAISTL(6)
      DIMENSION XBLEED(6)
      DATA NSTAGE/1,2,3,4,5,6,7,8,9,10,11,12/,  RU/1545.44/, PI/3.141592
     17/, G/32.1740/, AJ/778.12/, RAD/57.29578/
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
C                                                                     C
C INPUT DATA
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C NS            NUMBER OF STAGE
C RRHUB(I)      ROTOR INLET RUDIUS AT HUB FOR I-TH STAGE IN INCH
C RC(I)        ROTOR CHORD FOR I-TH STAGE IN INCH
C RBLADE(I)     NUMBER OF ROTOR BLADE FOR I-TH STAGE
C STAGER(I)     ROTOR STAGER ANGLE FOR I-TH STAGE IN DEGREE.
C SRHUB(I)      STATOR INLET RUDIUS AT HUB FOR I-TH STAGE IN INCH
C SC(I)         STATOR CHORD FOR I-TH STAGE IN INCH(I=NS+1,IGV)
C SBLADE(I)     NUMBER OF STATOR BLADE FOR I-TH STAGE (I=NS+1,IGV)
C SIGUMR(I)     SOLIDITY OF ROTOR FOR I-TH STAGE
C FNF           FRACTION OF DESIGN CORRECTED ROTOR SPEED FOR A PARTICULAR
C               SPEED
C XDIN          INITIAL WATER CONTENT (MASS FRACTION) OF SMALL DROPLET
C XDDIN         INITIAL WATER CONTENT (MASS FRACTION)  OF DARGE DROPLET
C ICENT         INDEX FOR CENTRIFUGAL CALCULATION (ICENT=1 WHEN XDIN=0
C               OTHERWISE ICENT=2)
C IICENT        SAME AS ICENT
C TOG           TOTAL TEMPERATURE AT COMPRESSR INLET IN RANKIN
C TOW           WATER DROPLET TEMPERATURE AT COMPRESSOR INLET IN RANKIN
C PO            TOTAL PRESSURE AT COMPRESSOR INLET IN LB/FT**2
C DIN           INITIAL WATER DROPLET DIAMETER IN MICRON(SMALL DROLLET)
C DDIN          INITIAL WATER DROPLET DIAMETER IN MICRON(LARGE DROPLET)
C FND           ROTOR ROTATIONAL SPEED AT DESIGN SPEED IN RPM
C T01D          DESIGN VALUE FOR COMPRESSOR INLET TOTAL TEMPERATURE
C               IN RANKIN
C P01D          DESIGN VALUE FOR COMPRESSOR INLET TOTAL PRESSURE
C               IN LB/FT**2
C XCH4          INITIAL METHANE CONTENT(MASS FRACTION)
C RHUMID        INITIAL RELATIVE HUMIDITY(PER CENT)
C FMWA          MOLECOLAR WEIGHT OF AIR
C FMWV          MOLECULAR WEIGHT OF WATER VAPOR
C FMWC          MOLECULAR WEIGHT OF METHANE
C PREB          PERCENT OF WATER THAT REBOUND AFTER IMPINGEMENT
C DLIMIT        MAX. DIAMETER FOR SMALL DROPLET IN MICRON
C STAGES(I)     STATOR STAGER ANGLE FOR I-TH STAGE IN DEGREE
C GAPR(I)       GAP BETWEEN I TH STAGE ROTOR AND I-1 TH STAGE STATOR
C               IN INCH
C GAPS(I)       GAP BETWEEN I TH STAGE STATOR AND I-1 TH STAGE ROTOR
C               IN INCH
C XBLEED(I)     AMOUNT OF BLEED AT I-TH STAGE OUTLET
C RRTIP(I)      ROTOR INLET TIP RADIUS FOR I-TH STAGE IN INCH
C SRTIP(I)      STATOR INLET TIP RADIUS FOR I-TH STAGE IN INCH
C IRAD          INDEX FOR RADIUS AT WHICH CALCULATION IS CARRIED OUT
C                 IRAD=1: TIP
C                 IRAD=2: MEAN
C                 IRAD=3: HUB
C RT(I)         RADIUS AT ROTOR INLET WHERE PERFORMANCE CALCULATION
C               IS CARRIED OUT WHEN IRAD=1,IN INCH
C RM(I)         RADIUS AT ROTOR INLET WHERE PERFORMANCE CALCULATION
C               IS CARRIED OUT WHEN IRAD=2,IN INCH
C RH(I)         RADIUS AT ROTOR INLET WHERE PERFORMANCE CALCULATION
C               IS CARRIED OUT WHEN IRAD=3,IN INCH
C ST(I)         RADIUS AT ROTOR OUTLET WHERE PERFORMANCE CALCULATION
C               IS CARRIED OUT WHEN IRAD=1,IN INCH
C SM(I)         RADIUS AT ROTOR OUTLET WHERE PERFORMANCE CALCULATION
C               IS CARRIED OUT WHEN IRAD=2,IN INCH
C SH(I)         RADIUS AT ROTOR OUTLET WHERE PERFORMANCE CALCULATION
C               IS CARRIED OUT WHEN IRAD=3,IN INCH
C BLOCK(I)      BLOCKAGE FACTOR FOR ROTOR
C BLOCKS(I)     BLOCKAGE FACTOR FOR STATOR
C BET1MR(I)     BLADE METAL ANGLE AT ROTOR INLET FOR I-TH STAGE IN DEG
C BET2MR(I)     BLADE METAL ANGLE AT ROTOR OUTLET FOR I-TH STAGE IN DEG
C BET1MS(I)     BLADE METAL ANGLE AT STATOR INLET FOR I-TH STAGE IN DEG
C BET2MS(I)     BLADE METAL ANGLE AT STATOR OUTLET FOR I-TH STAGE IN DEG
C DSMASS        DESIGN MASS FLOW RATE(LB/SEC)
C PR12D(I)      DESIGN TOTAL PRESSURE RATIO FOR I-TH STAGE ROTOR
C PR13D(I)      DESIGN TOTAL PRESSURE RATIO FOR I-TH STAGE
```

```
C ETARD(I)     DESIGN ADIABATIC EFFICIENCY FOR I-TH STAGE ROTOR
C SAREA(I)     STREAM TUBE AREA AT I-TH STAGE ROTOR INLET IN FT**2
C SAREAS(I)    STREAM TUBE AREA AT I-TH STAGE STATOR INLET IN FT**2
C              CALCULATION
C XBLEED(I)    BLEED(MASS FRACTION)
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C READ INPUT DATA                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,99) NS
   99 FORMAT(I1)
      NS1=NS+1
      READ(5,100) (RRHUB(I),I=1,NS)
  100 FORMAT (6F5.3)
      READ(5,111)(RC(I),I=1,NS)
  111 FORMAT(6F5.3)
      READ(5,112) (RBLADE(I),I=1,NS)
  112 FORMAT(6F5.2)
      READ(5,113)(STAGER(I) ,I=1,NS)
  113 FORMAT(6F5.2)
      READ(5,114)(SRHUB(I),I=1,7)
  114 FORMAT(7F5.3)
      READ(5,115) (SC(I),I=1,7)
  115 FORMAT(7F5.3)
      READ(5,116)(SBLADE(I),I=1,7)
  116 FORMAT(7F5.2)
      READ(5,117)(SIGUMR(I),I=1,NS)
  117 FORMAT(6F5.3)
      READ(5,122)(SIGUMS(I) ,I=1,NS1)
  122 FORMAT(7F5.3)
      READ(5,124)(BET2SS(I),I=1,NS1)
  124 FORMAT(7F5.2)
      READ(5,127) FNF
  127 FORMAT(F8.2)
      READ(5,128) XDIN,ICENT,XDDIN,IICENT
  128 FORMAT(F5.3,I1,F5.3,I1)
      READ(5,129) TOG,TOW,PO
  129 FORMAT(3F7.2)
      READ(5,130) DIN,DDIN
  130 FORMAT(2F6.1)
      READ(5,132) FND,T01D,P01D
  132 FORMAT(F7.1,2F7.2)
      READ(5,133) XCH4,RHUMID
  133 FORMAT(F5.3,F10.5)
      READ(5,134) FMWA,FMWV,FMWC
  134 FORMAT(3F7.3)
      READ(5,135) PREB,DLIMIT
  135 FORMAT(F5.1,F7.1)
      READ(5,140) (STAGES(I),I=1,NS1)
  140 FORMAT(7F5.2)
      READ(5,141) (GAPR(I),I=1,NS)
  141 FORMAT(6F7.5)
      READ(5,142) (GAPS(I),I=1,NS)
  142 FORMAT(6F7.5)
      READ(5,146) (RRTIP(I),I=1,NS)
  146 FORMAT(6F6.3)
      READ(5,147) (SRTIP(I),I=1,NS1)
  147 FORMAT(7F6.3)
      READ(5,1491) IRAD
 1491 FORMAT(I1)
      READ(5,1492) (RT(I),I=1,NS)
 1492 FORMAT(6F5.3)
      READ(5,1493) (RM(I),I=1,NS)
 1493 FORMAT(6F5.3)
      READ(5,1494) (RH(I),I=1,NS)
 1494 FORMAT(6F5.3)
      READ(5,1495) (ST(I),I=1,NS)
 1495 FORMAT(6F5.3)
```

```
      READ(5,1496) (SM(I),I=1,NS)
 1496 FORMAT(6F5.3)
      READ(5,1497) (SH(I),I=1,NS)
 1497 FORMAT(6F5.3)
      READ(5,1498) (BLOCK(I),I=1,NS)
 1498 FORMAT(6F5.3)
      READ(5,1499) (BLOCKS(I),I=1,NS1)
 1499 FORMAT(7F5.3)
      READ(5,1502) (BET1MR(I),I=1,NS)
 1502 FORMAT(6F5.2)
      READ(5,1503) (BET2MR(I),I=1,NS)
 1503 FORMAT(6F5.2)
      READ(5,1504) (BET1MS(I),I=1,NS1)
 1504 FORMAT(7F5.2)
      READ(5,1505) (BET2MS(I),I=1,NS1)
 1505 FORMAT(7F5.2)
      READ(5,1506) DSMASS
 1506 FORMAT(F10.6)
      READ(5,1507) (PR12D(I),I=1,NS)
 1507 FORMAT(6F5.3)
      READ(5,1508) (PR13D(I),I=1,NS)
 1508 FORMAT(6F5.3)
      READ(5,1509) (ETARD(I),I=1,NS)
 1509 FORMAT(6F5.3)
      READ(5,1511) (SAREA(I),I=1,NS)
 1511 FORMAT(6F10.7)
      READ(5,1512) (SAREAS(I),I=1,NS1)
 1512 FORMAT(7F10.7)
      READ(5,1513) (XBLEED(I),I=1,NS)
 1513 FORMAT(6F5.2)
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C OTHER INPUT DATA
      FNFN=FNF*100.0
      WKDONE=1.0
      IPRINT=1
      DO 1530 I=1,NS
      FMR1(I)=0.6
      FMA2(I)=0.6
 1530 CONTINUE
      AK1=1.0
      AK2=0.0
      AK3=0.0
      AAAIGV=SAREA(1)
      RU=1545.3
      RHOW=62.54
      CPW=1.0
      RA=RU/FMWA
      RV=RU/FMWV
      RCH=RU/FMWC
      DELV=0.0
      DELVU2=10.0
      DELVL2=10.0
      REAVE=0.0
      GC=32.174
      AJ=778.16
      PAI=3.1415926
      DO 150 I=1,NS
      AAREA(I)=PAI*((RRTIP(I)/12.0)**2-(RRHUB(I)/12.0)**2)*BLOCK(I)
      AAREAS(I)=PAI*(SRTIP(I)**2-SRHUB(I)**2)/144.0*BLOCKS(I)
      DELZ(I)=(RC(I)+SC(I))/12.0
  150 CONTINUE
      NS1=NS+1
      AAREAS(NS1)=PAI*(SRTIP(NS1)**2-SRHUB(NS1)**2)/144.0*BLOCKS(NS1)
      AAAR1T=AAREA(1)
       DO 152 I=1,NS
      AREA(I)=SAREA(I)
      AREAS(I)=SAREAS(I)
  152 CONTINUE
      AREAS(NS1)=SAREAS(NS1)
      FN=FND*FNF*SQRT(TOG/518.7)
```

```
      OT01G=TOG                                                          MAIN
      OT01D=TOW                                                          MAIN
      OP01=PO                                                            MAIN
      CRPM=FNF*FND                                                       MAIN
      DO 151 I=1,NS                                                      MAIN
      UTIP(I)=RT(I)/12.0*2.0*PAI*FND/60.0                                MAIN
      UTIPG(I)=RRTIP(I)/12.0*2.0*PAI*FND/60.0                            MAIN
      UTIP2(I)=ST(I)/12.0*2.0*PAI*FND/60.0                               MAIN
      UTIPD(I)=RT(I)/12.0*2.0*PAI*FND/60.0                               MAIN
      UOU(I)=(UTIP(I)/UTIPD(I))**2                                       MAIN
      UMEAN(I)=RM(I)/12.0*2.0*PAI*FND/60.0                               MAIN
      UMEAN2(I)=SM(I)/12.0*2.0*PAI*FND/60.0                              MAIN
      UHUB(I)=RH(I)/12.0*2.0*PAI*FND/60.0                                MAIN
      UHUB2(I)=SH(I)/12.0*2.0*PAI*FND/60.0                               MAIN
      IF(IRAD.EQ.1) U(I)=UTIP(I)                                         MAIN
      IF(IRAD.EQ.2) U(I)=UMEAN(I)                                        MAIN
      IF(IRAD.EQ.3) U(I)=UHUB(I)                                         MAIN
      IF(IRAD.EQ.1) UU2(I)=UTIP2(I)                                      MAIN
      IF(IRAD.EQ.2) UU2(I)=UMEAN2(I)                                     MAIN
      IF(IRAD.EQ.3) UU2(I)=UHUB2(I)                                      MAIN
      IF(IRAD.EQ.1) RADI1(I)=RT(I)                                       MAIN
      IF(IRAD.EQ.1) RADI2(I)=ST(I)                                       MAIN
      IF(IRAD.EQ.2) RADI1(I)=RM(I)                                       MAIN
      IF(IRAD.EQ.2) RADI2(I)=SM(I)                                       MAIN
      IF(IRAD.EQ.3) RADI1(I)=RH(I)                                       MAIN
      IF(IRAD.EQ.3) RADI2(I)=SH(I)                                       MAIN
  151 CONTINUE                                                           MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++           MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C PRINT OUT OF INPUT DATA                                                MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      WRITE(6,1600)                                                      MAIN
 1600 FORMAT(1H1,5X,≠***************************** INPUT DATA ********** MAIN
     $***************************≠)                                      MAIN
      WRITE(6,1610) NS                                                   MAIN
 1610 FORMAT(1H0,1X,≠NS(NUMBER OF STAGE)=≠,I2)                           MAIN
      IF(IUNIT.EQ.1) WRITE(6,1601)                                       MAIN
 1601 FORMAT(1H ,1X,≠UNIT=ENGLISH UNIT≠)                                 MAIN
      IF(IUNIT.EQ.2) WRITE(6,1602)                                       MAIN
 1602 FORMAT(1H ,1X,≠UNIT=METRIC UNIT≠)                                  MAIN
      WRITE(6,1603) IPERFM                                               MAIN
 1603 FORMAT(1H ,1X,≠IPERFM=≠,I1)                                        MAIN
      IF(IRAD.EQ.1) WRITE(6,1604)                                        MAIN
 1604 FORMAT(1H ,1X,≠PERFORMANCE AT TIP≠)                                MAIN
      IF(IRAD.EQ.2) WRITE(6,1605)                                        MAIN
 1605 FORMAT(1H ,1X,≠PERFORMANCE AT MEAN≠)                               MAIN
      IF(IRAD.EQ.3) WRITE(6,1606)                                        MAIN
 1606 FORMAT(1H ,1X,≠PERFORMANCE AT HUB≠)                                MAIN
      WRITE(6,1620)                                                      MAIN
 1620 FORMAT(1H0,14X,≠1≠,5X,≠2≠,5X,≠3≠,5X,≠4≠,5X,≠5≠,5X,≠6≠)              MAIN
      WRITE(6,1630) (RRHUB(I),I=1,NS)                                    MAIN
 1630 FORMAT(1H ,1X,≠RRHUB(I)≠,3X,6(F5.3,1X))                            MAIN
      WRITE(6,1640) (RC(I),I=1,NS)                                       MAIN
 1640 FORMAT(1H ,1X,≠RC(I)≠,6X,6(F5.3,1X))                               MAIN
      WRITE(6,1650) (RBLADE(I),I=1,NS)                                   MAIN
 1650 FORMAT(1H ,1X,≠RBLADE(I)≠,2X,6(F5.2,1X))                           MAIN
      WRITE(6,1660) (STAGER(I),I=1,NS)                                   MAIN
 1660 FORMAT(1H ,1X,≠STAGER(I)≠,2X,6(F5.2,1X))                           MAIN
      WRITE(6,1661) (STAGES(I),I=1,NS)                                   MAIN
 1661 FORMAT(1H ,1X,≠STAGES(I)≠,2X,6(F5.2,1X))                           MAIN
      WRITE(6,1670) (SRHUB(I),I=1,NS1)                                   MAIN
 1670 FORMAT(1H ,1X,≠SRHUB(I)≠,3X,7(F5.3,1X))                            MAIN
      WRITE(6,1680) (SC(I),I=1,NS)                                       MAIN
 1680 FORMAT(1H ,1X,≠SC(I)≠,6X,6(F5.3,1X))                               MAIN
      WRITE(6,1690) (SBLADE(I),I=1,NS)                                   MAIN
 1690 FORMAT(1H ,1X,≠SBLADE(I)≠,2X,6(F5.2,1X))                           MAIN
      WRITE(6,1700) (SIGUMR(I),I=1,NS)                                   MAIN
 1700 FORMAT(1H ,1X,≠SIGUMR(I)≠,2X,6(F5.3,1X))                           MAIN
```

```
      WRITE(6,1750) (SIGUMS(I),I=1,NS)
 1750 FORMAT(1H ,1X,≠SIGUMS(I)≠,2X,6(F5.3,1X))
      WRITE(6,1792) (FAISTL(I),I=1,NS)
 1792 FORMAT(1H ,1X,≠FAISTL(I)≠,2X,6(F5.3,1X))
      WRITE(6,1795) (GAPR(I),I=1,NS)
 1795 FORMAT(1H ,1X,≠GAPR(I)≠,4X,6(F5.3,1X))
      WRITE(6,1796) (GAPS(I),I=1,NS)
 1796 FORMAT(1H ,1X,≠GAPS(I)≠,4X,6(F5.3,1X))
      WRITE(6,1798) (RRTIP(I),I=1,NS)
 1798 FORMAT(1H ,1X,≠RRTIP(I)≠,3X,6(F5.2,1X))
      WRITE(6,1799) (SRTIP(I),I=1,NS1)
 1799 FORMAT(1H ,1X,≠SRTIP(I)≠,3X,7(F5.2,1X))
      WRITE(6,1801) (RT(I),I=1,NS)
 1801 FORMAT(1H ,1X,≠RT(I)≠,6X,6(F5.3,1X))
      WRITE(6,1802) (RM(I),I=1,NS)
 1802 FORMAT(1H ,1X,≠RM(I)≠,6X,6(F5.3,1X))
      WRITE(6,1803) (RH(I),I=1,NS)
 1803 FORMAT(1H ,1X,≠RH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1804) (ST(I),I=1,NS)
 1804 FORMAT(1H ,1X,≠SH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1805) (SM(I),I=1,NS)
 1805 FORMAT(1H ,1X,≠SM(I)≠,6X,6(F5.3,1X))
      WRITE(6,1806) (SH(I),I=1,NS)
 1806 FORMAT(1H ,1X,≠SH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1807) (BLOCK(I),I=1,NS)
 1807 FORMAT(1H ,1X,≠BLOCK(I)≠,3X,6(F5.3,1X))
      WRITE(6,1808) (BLOCKS(I),I=1,NS)
 1808 FORMAT(1H ,1X,≠BLOCKS(I)≠,2X,6(F5.3,1X))
      WRITE(6,1811) (BET1MR(I),I=1,NS)
 1811 FORMAT(1H ,1X,≠BET1MR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1812) (BET2MR(I),I=1,NS)
 1812 FORMAT(1H ,1X,≠BET2MR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1813) (BET1MS(I),I=1,NS1)
 1813 FORMAT(1H ,1X,≠BET1MS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1814) (BET2MS(I),I=1,NS1)
 1814 FORMAT(1H ,1X,≠BET2MS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1815) (PR12D(I),I=1,NS)
 1815 FORMAT(1H ,1X,≠PR12D(I)≠,3X,6(F5.3,1X))
      WRITE(6,1816) (PR13D(I),I=1,NS)
 1816 FORMAT(1H ,1X,≠PR13D(I)≠,3X,6(F5.3,1X))
      WRITE(6,1817) (ETARD(I),I=1,NS)
 1817 FORMAT(1H ,1X,≠ETARD(I)≠,3X,6(F5.3,1X))
      IF(IAREA.EQ.2) WRITE(6,1821) (SAREA(I),I=1,NS)
 1821 FORMAT(1H ,1X,≠SAREA(I)≠,3X,6(F10.7,1X))
      IF(IAREA.EQ.2) WRITE(6,1822) (SAREAS(I),I=1,NS1)
 1822 FORMAT(1H ,1X,≠SAREAS(I)≠,2X,7(F10.7,1X))
      WRITE(6,1818)
 1818 FORMAT(1H1,5X,≠****************************** INPUT DATA **********
     $******************≠)
      WRITE(6,1800) FNF
 1800 FORMAT(1H0,1X,≠FNF(FRACTION OF DESIGN CORRECTED SPEED)=≠,F5.3)
      WRITE(6,1810) XDIN,XDDIN,RHUMID,XCH4
 1810 FORMAT(1H0,1X,≠XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=≠,F5.3
     $,/,2X,≠XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=≠,F5.3,/,
     $2X,≠RHUMID(INITIAL RELATIVE HUMIDITY)=≠,F6.2,1X,≠PER CENT≠,/,
     $2X,≠XCH4(INITIAL METHANE CONTENT)=≠,F5.3)
      WRITE(6,1820) TOG,TOW,PO
 1820 FORMAT(1H0,1X,≠TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)=≠,
     $F7.2,/,2X,≠TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)=≠,F7.2,/,
     $2X,≠PO(COMPRESSOR INLET TOTAL PRESSURE)=≠,F7.2)
      WRITE(6,1830) DIN,DDIN
 1830 FORMAT(1H0,1X,≠DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=≠,
     $F6.1,/,2X,≠DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)=≠,F6.1)
      WRITE(6,1850) FND
 1850 FORMAT(1H0,1X,≠FND(DESIGN ROTATIONAL SPEED)=≠,F7.1)
      WRITE(6,1851) DSMASS
 1851 FORMAT(1H0,1X,≠DSMASS(DESIGN MASS FLOW RATE)=≠,F10.4)
      WRITE(6,1860) TOG
 1860 FORMAT(1H0,1X,≠COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE)≠ ,
     $F7.2,1X,≠R≠)
```

```
      WRITE(6,1870) PO                                                  MAIN
 1870 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F7.2,1X,≠LB/FT**2 MAIN
     $≠)                                                                MAIN
      WRITE(6,1880) PREB                                                MAIN
 1880 FORMAT(1H0,1X,≠PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MAIN
     $MENT)=≠,F5.1,1X,≠PERCENT≠)                                        MAIN
      WRITE(6,1900) FN                                                  MAIN
 1900 FORMAT(1H0,1X,≠ROTOR SPEED=≠,F7.1,1X,≠RPM≠)                       MAIN
      WRITE(6,1910) CRPM,FNFN                                           MAIN
 1910 FORMAT(1H0,1X,≠CORRECTED ROTOR SPEED= ≠,F7.1,1X,≠RPM≠,≠(≠,2X,F5.1, MAIN
     $≠PER CENT OF DESIGN CORRECTED SPEED)≠)                            MAIN
      TG(1)=T01D                                                        MAIN
      P(1)=P01D                                                         MAIN
      CALL WICSPD(DSMASS,ISTAGE)                                        MAIN
      SPEEDF=FNF                                                        MAIN
      CALL CSINPT                                                       MAIN
      XW(1)=0.0                                                         MAIN
      CALL NASA                                                         MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C ROTER SPEED AND RADIUS                                                C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      DO 153 I=1,NS                                                     MAIN
      UTIP(I)=RT(I)/12.0*2.0*PAI*FN/60.0                                MAIN
      UTIPG(I)=RRTIP(I)/12.0*2.0*PAI*FN/60.0                            MAIN
      UTIP2(I)=ST(I)/12.0*2.0*PAI*FN/60.0                               MAIN
      UTIPD(I)=RT(I)/12.0*2.0*PAI*FND/60.0                              MAIN
      UOU(I)=(UTIP(I)/UTIPD(I))**2                                      MAIN
      UMEAN(I)=RM(I)/12.0*2.0*PAI*FN/60.0                               MAIN
      UMEAN2(I)=SM(I)/12.0*2.0*PAI*FN/60.0                              MAIN
      UHUB(I)=RH(I)/12.0*2.0*PAI*FN/60.0                                MAIN
      UHUB2(I)=SH(I)/12.0*2.0*PAI*FN/60.0                               MAIN
      IF(IRAD.EQ.1) U(I)=UTIP(I)                                        MAIN
      IF(IRAD.EQ.2) U(I)=UMEAN(I)                                       MAIN
      IF(IRAD.EQ.3) U(I)=UHUB(I)                                        MAIN
      IF(IRAD.EQ.1) UU2(I)=UTIP2(I)                                     MAIN
      IF(IRAD.EQ.2) UU2(I)=UMEAN2(I)                                    MAIN
      IF(IRAD.EQ.3) UU2(I)=UHUB2(I)                                     MAIN
      IF(IRAD.EQ.1) RADI1(I)=RT(I)                                      MAIN
      IF(IRAD.EQ.1) RADI2(I)=ST(I)                                      MAIN
      IF(IRAD.EQ.2) RADI1(I)=RM(I)                                      MAIN
      IF(IRAD.EQ.2) RADI2(I)=SM(I)                                      MAIN
      IF(IRAD.EQ.3) RADI1(I)=RH(I)                                      MAIN
      IF(IRAD.EQ.3) RADI2(I)=SH(I)                                      MAIN
  153 CONTINUE                                                          MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C MASS FLOE RATE                                                          MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      ISTAGE = 0                                                        MAIN
      N=1                                                               MAIN
  901 READ(5,200) FAI                                                   MAIN
  200 FORMAT(F7.5)                                                      MAIN
      IF(FAI.GT.1.0) GO TO 998                                          MAIN
      IF(IPRINT.EQ.2) WRITE(6,197) FAI                                  MAIN
  197 FORMAT(1H1,2X,≠FAI=≠,F7.5)                                        MAIN
      FAIO=FAI                                                          MAIN
      VZ=UTIPG(1)*FAI                                                   MAIN
      TG(1)=OT01G                                                       MAIN
      UZERO=0.0                                                         MAIN
      UUZERO=0.0                                                        MAIN
      RZERO=RRHUB(1)                                                    MAIN
      RRZERO=RRHUB(1)                                                   MAIN
      ITIP=0                                                            MAIN
      IITIP=0                                                           MAIN
      DAVE(N)=0.0                                                       MAIN
```

```
      DDAVE(N)=0.0
      TW(1)=OT01D
      TWW(1)=OT01D
      IF(XDIN.GT.0.0) DAVE(N)=DIN
      IF(XDDIN.GT.0.0) DDAVE(N)=DDIN
      IF(XDIN.GT.0.0) TW(1)=OT01D
      IF(XDDIN.GT.0.0) TWW(1)=OT01D
      P(1)=OP01
      TB(1) = WICBPT(TG(1), P(1))
      WS(1) = WICSH(TG(1) , P(1) )*RHUMID/100.0
      PW=WS(1)*P(1)/(WS(1)+0.6219)
      TDEW(1)=WICBPT(TG(1),PW)
      XW(1)=XDIN
      XWW(1)=XDDIN
      XWT(1)=XW(1)+XWW(1)
      XWTO=XWT(1)
      XV(1)=WS(1)/(1.0+WS(1))*(1.0-XWT(1)-XCH4)
      XA=1.0-XWT(1)-XV(1)-XCH4
      XG=XA+XV(1)+XCH4
      XAIN=XA
      XCH4IN=XCH4
      ISTAGE=1
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMAI=GAMMA
      RHOG(1)=P(1)/RMIX/TG(1)
      RHOA(1)=P(1)/RA/TG(1)
      AMASSM=-1.0
      AAA2=AAAIGV
      AAA3=AAAIGV
      CALL WICMAC(ISTAGE,AMASSM,TG(1),P(1),M,VZ,C,XWT(1),BET2SS(NS1),
     $RMIX,CPMIX,AAA3)
      RHOG(1)=(1.0+G2*M**2)**G3*RHOG(1)
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)
      MMASS = RHOM(1)*FAI*UTIPG(1)*AAA3
      MMASSO=MMASS
      WMASSO=MMASSO*XDIN
      WWMASO=MMASSO*XDDIN
      IF(IPRINT.EQ.2) WRITE(6,5558) MMASSO,XDIN,WMASSO,MMASS
 5558 FORMAT(1H0,2X,4(F10.5,2X))
      DAMY=OT01G/518.7
      DAMY2=OP01/(14.7*144.0)
      CMASS=MMASS*SQRT(DAMY)/DAMY2
      AMASS = XA * MMASS
      WMASS(1)=XW(1)*MMASS
      WWMASS(1)=XWW(1)*MMASS
      WTMASS(1)=XWT(1)*MMASS
      VMASS(1)=XV(1)*MMASS
      CHMASS=XCH4*MMASS
      GMASS(1)=MMASS-WTMASS(1)
      CMASS2=GMASS(1)*SQRT(DAMY)/DAMY2
      AMO=AMASS
      VMO=VMASS(1)
      CMO=CHMASS
      GMO=GMASS(1)
      WMO=WMASS(1)
      WWMO=WWMASS(1)
      WTMO=WTMASS(1)
      TLMO=GMO+WTMO
      TWMAS=WMASSO*AAAR1T/AAAIGV
      TWWMAS=WWMASO*AAAR1T/AAAIGV
      WMASTL=TWMAS+TWWMAS
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C INITIAL VALUES
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      TG(3)=TG(1)
      TW(3)=TW(1)
      TWW(3)=TWW(1)
```

```
      P(3)=P(1)
      TB(3)=TB(1)
      WS(3)=WS(1)
      TDEW(3)=TDEW(1)
      XV(3)=XV(1)
      XG=XA+XV(3)+XCH4
      XW(3)=XW(1)
      XWW(3)=XWW(1)
      VMASS(3)=VMASS(1)
      WMASS(3)=WMASS(1)
      WWMASS(3)=WWMASS(1)
      WCENT=WMASSO
      WWCENT=WWMASO
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C IGV                                                                  C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C IGV IMPINGEMENT
      CALL WICISS(7,RADI1(1), XW(1) , XG , RHOG(1),0.0,VZ,WW1,WW2,WW)
      AMIMPS=WW
      AMWAKS = AMIMPS * (1.0-PREB)
      AMREBS=AMIMPS*PREB
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C IGV WAKE
      N=2
      DAVE(2)=DAVE(1)
      DDAVE(2)=DDAVE(1)
      ALFA3=BET2SS(NS1)*(FAID/FAI)**(1.0/7.0)
      DWAKEM=0.0
      IF(XDIN.GT.0.0.OR.XDDIN.GT.0.0) GO TO 628
      GO TO 629
  628 CALL WICWAK(RHOG(1),VZ,DWAKE,DWAKEM)
  629 CONTINUE
C  +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C IGV OUTLET
      WMASS(3) = WMASS(1)
      XW(3) = XW(1)
      PRATIO=1.0
      TRATIO=1.0
      EFF=1.0
      AMIMPR=0.0
      AMREBR=0.0
      AMWAKR=0.0
      DELTGW=0.0
      DELTDW=0.0
      DELTGH=0.0
      DELTDH=0.0
      DELT=0.0
      DELP=0.0
      DMDTAV=0.0
      XV(3)=XV(1)
      XW(3)=XW(1)
      XWW(3)=XWW(1)
      WMASS(3) = WMASS(1)
      WWMASS(3)=WWMASS(1)
      VMASS(3) = VMASS(1)
      WS(3) = WS(1)
      TDEW(3)=TDEW(1)
      RHOA(3) = RHOA(1)
      RHOM(3) = RHOM(1)
      RHOG(3) = RHOG(1)
      TG(3) = TG(1)
      TW(3) = TW(1)
      TWW(3)=TWW(1)
      P(3) = P(1)
      TB(3) = TB(1)
      XV(2)=0.0
      XW(2) = 0.0
```

```
      XWW(2)=0.0
      WMASS(2) = 0.0
      WWMASS(2)=0.0
      VMASS(2) = 0.0
      WS(2) = 0.0
      RHOA(2)=0.0
      RHOM(2) = 0.0
      RHOG(2)= 0.0
      TG(2)=0.0
      TW(2) =0.0
      TWW(2)=0.0
      P(2) = 0.0
      TB(2) = 0.0
      TDEW(2)=0.0
      GAMMAO=GAMMA
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C IGV OUTLET
      IF(IPRINT.EQ.2) WRITE(6,300) ISTAGE
  300 FORMAT(1H0,5X,≠ISTAGE=≠,I1,2X,≠(IGV)≠)
      IF(IPRINT.EQ.2) WRITE(6,301) PRATIO,TRATIO,EFF
  301 FORMAT(1H0,5X,3(F12.5,5X))
      IF(IPRINT.EQ.2) WRITE(6,302) FAI, VZ, XA
  302 FORMAT(1H0,5X,3(F12.5,5X))
      IF(IPRINT.EQ.2) WRITE(6,303) MMASS, AMASS, AMIMPS, AMREBS, AMWAKS,
     1AMIMPR, AMREBR, AMWAKR
  303 FORMAT(1H0,5X,8(F12.5,2X))
      IF(IPRINT.EQ.2) WRITE(6,304) DELTGW,DELTDW,DELTGH,DELTDH,DMDTAV,
     $DELT,DELP
  304 FORMAT(1H0,5X,7(F12.5,2X))
      IF(IPRINT.EQ.2) WRITE(6,305) XV(1), XV(2), XV(3)
  305 FORMAT(1H0,5X,≠XV=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,306) XW(1), XW(2) , XW(3)
  306 FORMAT(1H0,5X,≠XW=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,307) WMASS(1), WMASS(2) , WMASS(3)
  307 FORMAT(1H0,5X,≠WMASS=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,308) VMASS(1) , VMASS(2) , VMASS(3)
  308 FORMAT(1H0,5X,≠VMASS=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,309) WS(1) , WS(2) , WS(3)
  309 FORMAT(1H0,5X,≠WS=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,310) RHOA(1) , RHOA(2) , RHOA(3)
  310 FORMAT(1H0,5X,≠RHOA=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,311) RHOM(1), RHOM(2),RHOM(3)
  311 FORMAT(1H0,5X,≠RHOM=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,312) RHOG(1),RHOG(2),RHOG(3)
  312 FORMAT(1H0,5X,≠RHOG=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,313) TG(1),TG(2),TG(3)
  313 FORMAT(1H0,5X,≠TG=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,314) TW(1),TW(2),TW(3)
  314 FORMAT(1H0,5X,≠TW=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,315) P(1),P(2),P(3)
  315 FORMAT(1H0,5X,≠P=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,316) TB(1),TB(2),TB(3)
  316 FORMAT(1H0,5X,≠TB=≠,3(F20.10,5X))
      IF(IPRINT.EQ.2) WRITE(6,321) TDEW(1),TDEW(2),TDEW(3)
  321 FORMAT(1H0,5X,≠TDEW=≠,3(F20.10,5X))
      RHOG(2)=RHOG(1)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C ROTER INLET
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  900 ISTAGE=ISTAGE+1
      IF(IPRINT.EQ.2) WRITE(6,8001) FAIO,ISTAGE
 8001 FORMAT(1H1,1X,≠**********************  ≠,1X,
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F5.3,1X,≠(ISTAGE= ≠,I2,1X,
     $≠)≠,2X,≠************************≠)
      TG(1)=TG(3)
      TW(1)=TW(3)
      TWW(1)=TWW(3)
```

```
      P(1)=P(3)                                                         MAIN
      TB(1)=TB(3)                                                       MAIN
      RHOA(1)=P(1)/RA/TG(1)                                             MAIN
      WS(1)=WS(3)                                                       MAIN
      TDEW(1)=TDEW(3)                                                   MAIN
      XV(1)=XV(3)                                                       MAIN
      XCH4=CHMASS/MMASS                                                 MAIN
      XA=AMASS/MMASS                                                    MAIN
      XG=XA+XV(1)+XCH4                                                  MAIN
      XAIR(1)=XA                                                        MAIN
      XMETAN(1)=XCH4                                                    MAIN
      XGAS(1)=XG                                                        MAIN
      XW(1)=XW(3)                                                       MAIN
      XWW(1)=XWW(3)                                                     MAIN
      XWT(1)=XW(1)+XWW(1)                                               MAIN
      VMASS(1)=VMASS(3)                                                 MAIN
      WMASS(1)=WMASS(3)                                                 MAIN
      WWMASS(1)=WWMASS(3)                                               MAIN
      WTMASS(1)=WMASS(1)+WWMASS(1)                                      MAIN
      MMASS=AMASS+CHMASS+VMASS(1)+WTMASS(1)                             MAIN
      TMASS(1)=MMASS                                                    MAIN
      GMASS(1)=TMASS(1)-WTMASS(1)                                       MAIN
      ALFA1=ALFA3                                                       MAIN
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)        MAIN
      GAMMAS=GAMMA                                                      MAIN
      AAA1=AAA3                                                         MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C STAGE PERFORMANCE CALCULATION                                          MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      JPERFM=2                                                          MAIN
      DAMY=0.0                                                          MAIN
      IF(WTMASS(1).GT.1.0E-4)                                           MAIN
     $DAMY=WWMASS(1)/WTMASS(1)                                          MAIN
      IF(DAMY.GT.0.20) JPERFM=3                                         MAIN
      IF(IPRINT.EQ.2) WRITE(6,8000) JPERFM                              MAIN
 8000 FORMAT(1H0,≠ STAGE PERFORMANCE CALCULATION (JPERFM=≠,I2,≠ )≠)     MAIN
      IF(JPERFM.EQ.2) GO TO 1301                                        MAIN
      IF(JPERFM.EQ.3) GO TO 1302                                        MAIN
 1301 CALL CSOUPT(FAIO,ISTAGE,MMASS,ALFA1,BETA1,BETA2,VZ,ALFA2,ALFA3,   MAIN
     XDELTG,DELTW,W1,W2,V1,V2)                                          MAIN
      GO TO 1303                                                        MAIN
 1302 CALL COUPT2(FAIO,ISTAGE,GMASS(1),ALFA1,BETA1,BETA2,VZ,ALFA2,      MAIN
     $ALFA3,DELTG,DELTW,W1,W2,V1,V2)                                    MAIN
 1303 CONTINUE                                                          MAIN
      DELTG1=DELTG                                                      MAIN
      DELTW1=DELTW                                                      MAIN
      IF(VZ.LT.0.0.OR.VZ.GT.1000.0) WRITE(6,1304) VZ                    MAIN
 1304 FORMAT(1H0,1X,≠AXIAL VELOCITY IS TOO HIGH OR TOO LOW≠,≠VZ=≠,      MAIN
     $F10.5)                                                            MAIN
      IF(VZ.LT.0.0.OR.VZ.GT.1000.0) GO TO 901                           MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C ROTOR IMPINGEMENT                                                    C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C ROTOR IMPINGEMENT(SMALL DROPLET)                                       MAIN
      IF(IPRINT.EQ.2) WRITE(6,8010)                                     MAIN
 8010 FORMAT(1H1,≠ ROTOR IMPINGEMENT(SMALL DROPLET)≠)                   MAIN
      CALL WICIRS(ISTAGE,RADI1(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,   MAIN
     $WW2,WW)                                                           MAIN
      AMIMPR=WW                                                         MAIN
      IF(AMIMPR.LT.0.0) AMIMPR=0.0                                      MAIN
      IF(AMIMPR.GT.WMASS(1)) AMIMPR=WMASS(1)                            MAIN
      AMREBR=AMIMPR*PREB/100.0                                          MAIN
      AMWAKR=AMIMPR*(1.0-PREB/100.0)                                    MAIN
      AMNOIR=WMASS(1)-AMIMPR                                            MAIN
```

```
      XWNOIR=AMNOIR/MMASS
      XWREBR=AMREBR/MMASS
      XWWAKR=AMWAKR/MMASS
      IF(IPRINT.EQ.2) WRITE(6,609) AMIMPR,AMREBR,AMWAKR,AMNOIR,
     $XWNOIR,XWREBR,XWWAKR
  609 FORMAT(1H ,7(F12.5,1X))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C ROTOR IMPINGEMENT(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8020)
 8020 FORMAT(1H0,≠ ROTOR IMPINGEMENT(LARGE DROPLET)≠)
      CALL WICIRL(ISTAGE,RADI1(ISTAGE),XWW(1),XG,RHOG(1),BETA1,W1,WW1,WW
     $2,WW)
      BMIMPR=WW
      IF(BMIMPR.LT.0.0) BMIMPR=0.0
      IF(BMIMPR.GT.WWMASS(1)) BMIMPR=WWMASS(1)
      BMREBR=BMIMPR*PREB/100.0
      BMWAKR=BMIMPR*(1.0-PREB/100.0)
      BMNOIR=WWMASS(1)-BMIMPR
      XWWB=0.0
      IF(WWMASS(1).GT.1.0E-6) XWWB=BMWAKR/WWMASS(1)
      XWWNOR=BMNOIR/MMASS
      XWWRER=BMREBR/MMASS
      XWWWAR=BMWAKR/MMASS
      IF(IPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR,
     $XWWRER,XWWWAR
 6090 FORMAT(1H ,7(F12.5,1X))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C ROTOR WAKE
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPRINT.EQ.2) WRITE(6,8030)
 8030 FORMAT(1H0,≠ ROTOR WAKE≠)
      N=N+1
      ALFA=BETA2
      DWAKEM=0.0
      IF(AMWAKR.GT.0.0) GO TO 630
      GO TO 631
  630 CALL WICWAK(RHOG(1),W2,DWAKE,DWAKEM)
  631 D1=DWAKEM
      IF(D1.LT.0.0) D1=0.0
      IF(D1.GT.DIN) D1=DIN
      AMING1=AMWAKR
      ALFA=BETA2
      RDELV1=DELVU2
      DWAKEM=0.0
      IF(BMWAKR.GT.0.0) GO TO 6310
      GO TO 6311
 6310 CALL WICWAK(RHOG(1),RDELV1,DWAKE,DWAKEM)
 6311 D2=DWAKEM
      IF(D2.LT.0.0) D2=0.0
      IF(D2.GT.DDIN) D2=DDIN
      RUP2=(90.0-BETA2)/180.0
      AMING2=BMWAKR*RUP2
      RDELV2=DELVL2
      DWAKEM=0.0
      IF(BMWAKR.GT.0.0) GO TO 6312
      GO TO 6313
 6312 CALL WICWAK(RHOG(1),RDELV2,DWAKE,DWAKEM)
 6313 D3=DWAKEM
      IF(D3.LT.0.0) D3=0.0
      IF(D3.GT.DDIN) D3=DDIN
      RLOW2=(90.0+BETA2)/180.0
      AMING3=BMWAKR*RLOW2
      WMASSS=WMASS(1)-AMWAKR
      WMASSL=WWMASS(1)-BMWAKR
      CALL WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DDAVE(1
     $),DAVE(1),D1,D2,D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)
      WWMASS(2)=AMLGE
```

```
      WMASS(2)=AMSLL
      IF(WMASS(2).LT.0.0) WMASS(2)=0.0
      IF(WWMASS(2).LT.0.0) WWMASS(2)=0.0
      WTMASS(2)=WWMASS(2)+WMASS(2)
      VMASS(2)=VMASS(1)
      MMASS=AMASS+CHMASS+VMASS(2)+WTMASS(2)
      TMASS(2)=MMASS
      GMASS(2)=TMASS(2)-WTMASS(2)
      DAVE(N)=DSLL
      DDAVE(N)=DLGE
      XW(2)=WMASS(2)/MMASS
      XWW(2)=WWMASS(2)/MMASS
      XWT(2)=WTMASS(2)/MMASS
      XV(2)=XV(1)
      XCH4=CHMASS/MMASS
      XA=AMASS/MMASS
      XG=XA+XV(2)+XCH4
      XAIR(2)=XA
      XMETAN(2)=XCH4
      XGAS(2)=XG
      WS(2)=VMASS(2)/AMASS
      PW=WS(2)*P(2)/(WS(2)+0.6219)
      TDEW(2)=WICBPT(TG(2),PW)
      RHOA(2)=P(2)/RA/TG(2)
      CALL WICPRP(XA,XV(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)
      RHOG(2)=P(2)/RMIX/TG(2)
      IF(JPERFM.NE.3) BMASS=MMASS
      IF(JPERFM.EQ.3) BMASS=GMASS(2)
      CALL WICMAC(ISTAGE,BMASS,TG(2),P(2),M,VZ,C,XWT(2),ALFA2,
     $RMIX,CPMIX,AAA2)
      RHOG(2)=(1.0+G2*M**2)**G3*RHOG(2)
      RHOM(2)=1.0/((1.0-XWT(2))/RHOG(2)+XWT(2)/RHOW)
      RHOA(2)=(1.0+G2*M**2)**G3*RHOA(2)
      IF(IPRINT.EQ.2) WRITE(6,614) VZ,ALFA,D1,D2,D3,WWMASS(2),
     $WMASS(2),VMASS(2),XW(2),XV(2)
  614 FORMAT(1H ,10(F12.5,1X))
      IF(IPRINT.EQ.2) WRITE(6,615)WS(2),DAVE(N),DDAVE(N),RHOM(2),RHOA
     $(2),RHOM(2),RHOG(2)
  615 FORMAT(1H ,7(F12.5,1X))
      IF(VZ.LT.0.0.OR.VZ.GT.1500.0) WRITE(6,6150)
 6150 FORMAT(1H0,≠VZ IS TOO HIGH OR TOO LOW: VZ=≠,F10.4)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C CENTRIFUGAL ACTION IN ROTOR                                          C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C CENTRIFUGAL EFFECT IN ROTOR(SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8040)
 8040 FORMAT(1H0,≠CENTRIFUGAL ACTION IN ROTOR (SMALL DROPLET)≠)
      DELMW=0.0
      DELMAS=0.0
      RW=0.0
      RWW=0.0
      IF(WTMASS(1).GT.1.0E-6) RW=WMASS(1)/WTMASS(1)
      IF(WTMASS(1).GT.1.0E-6) RWW=WWMASS(1)/WTMASS(1)
      AMASW=(WMASTL-WCENT-WWCENT)*RW
      BMASW=(WMASTL-WCENT-WWCENT)*RWW*XWWB
      IF(DAVE(N-1).LT.1.0E-6) GO TO 996
      DD=DAVE(N-1)
      DELZZ=RC(ISTAGE)/12.0
      ALFAAV=(BETA1+BETA2)/2.0
      IRS=2
      RHOGAS=RHOG(2)
      RHUB=RRHUB(ISTAGE)
      CALL WICCEN(RZERO,UZERO,DD,VZ,DELZZ,ALFAAV ,FN,IRS,RHOGAS,
     1RHUB,R2,U2,ITIP,VZTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))
      CALL WICDMS(IPRINT,IRAD,WMASS(1),AMASW,AMASW,RZERO,R2,AAREA(ISTA
     $GE),RADI1(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)
      WCENT=DELMAS
```

```
      RZERO=R2
      UZERO=U2
  996 DELMW=DELMAS
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C CENTRIFUGAL EFFECT IN ROTOR(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8050)
 8050 FORMAT(1H0,≠ CENTRIFUGAL ACTION IN ROTOR (LARGE DROPLET)≠)
      DELMAS=0.0
      DELMWW=0.0
      IF(DDAVE(N-1).LT.1.0E-6) GO TO 9996
      DD=DDAVE(N-1)
      DELZZ=RC(ISTAGE)/12.0
      ALFAAV=0.0
      IIRS=2
      RHOGAS=RHOG(2)
      RHUB=RRHUB(ISTAGE)
      CALL WICCEN(RRZERO,UUZERO,DD,VZ,DELZZ,ALFAAV ,FN,IIRS,RHOGAS,
     1RHUB,R2,U2,IITIP,VZTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))
      CALL WICDML(IPRINT,IRAD,WWMASS(1),BMASW,BMASW,RRZERO,R2,AAREA(IS
     $TAGE),RADI1(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)
      RRZERO=R2
      UUZERO=U2
 9996 DELMWW=DELMAS
      WM=WMASS(2)
      WWM=WWMASS(2)
      WMASS(2)=WMASS(2)+DELMW
      WWMASS(2)=WWMASS(2)+DELMWW
      WTMASS(2)=WMASS(2)+WWMASS(2)
      IF(WTMASS(2).GT.WMASTL) TT=WTMASS(2)/WMASTL
      IF(WTMASS(2).GT.WMASTL) WMASS(2)=WMASS(2)/TT
      IF(WTMASS(2).GT.WMASTL) WWMASS(2)=WWMASS(2)/TT
      DELMW=WMASS(2)-WM
      DELMWW=WWMASS(2)-WWM
      WTMASS(2)=WMASS(2)+WWMASS(2)
      DELMAS=WTMASS(2)-WTMASS(1)
      MMASS=MMASS+DELMAS
      XW(2)=WMASS(2)/MMASS
      XWW(2)=WWMASS(2)/MMASS
      XV(2)=VMASS(2)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(2)+XCH4
      DELVUM=RHOG(2)/RHOW*DELMAS
      AMASS=AMASS-DELVUM*(AMASS/GMASS(2))
      VMASS(2)=VMASS(2)-DELVUM*(VMASS(2)/GMASS(2))
      CHMASS=CHMASS-DELVUM*(CHMASS/GMASS(2))
      MMASS=AMASS+VMASS(2)+CHMASS+WTMASS(2)
      WS(2)=VMASS(2)/MMASS
      WCENT=WCENT+DELMW
      WWCENT=WWCENT+DELMWW
      IF(WMASS(2).LT.1.0E-6) DAVE(N)=0.0
      IF(WWMASS(2).LT.1.0E-6) DDAVE(N)=0.0
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C STATOR IMPINGEMENT                                                   C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C STATOR IMPINGEMENT(SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8060)
 8060 FORMAT(1H0,≠ STATOR IMPINGEMENT (SMALL DROPLET)≠)
      CALL WICISS(ISTAGE,RADI2(ISTAGE),XW(2),XG,RHOG(2),ALFA2,V2,
     $WW1,WW2,WW)
      AMIMPS=WW
      IF(AMIMPS.GT.WMASS(2)) AMIMPS=WMASS(2)
      IF(AMIMPS.LT.0.0) AMIMPS=0.0
      AMREBS=AMIMPS*PREB/100.0
      AMWAKS=AMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,617) XW(2),XG,RHOG(2),V2,WW,AMIMPS,AMRE
     $BS,AMWAKS
```

```
  617 FORMAT(1H ,8(F12.5,1X))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C STATOR IMPINGEMENT(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8070)
 8070 FORMAT(1H0,≠ STATOR IMPINGEMENT (LARGE DROPLET)≠)
      CALL WICISL(ISTAGE,RADI2(ISTAGE),XWW(2),XG,RHOG(2),ALFA2,V2,WW1
     $,WW2,WW)
      BMIMPS=WW
      IF(BMIMPS.LT.0.0) BMIMPS=0.0
      IF(BMIMPS.GT.WWMASS(2)) BMIMPS=WWMASS(2)
      BMREBS=BMIMPS*PREB/100.0
      BMWAKS=BMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2),XA,RHOA(2),VZ,WW,BMIMPS,BM
     $REBS,BMWAKS
 6617 FORMAT(1H ,8(F12.5,1X))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C STATOR WAKE
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPRINT.EQ.2) WRITE(6,8080)
 8080 FORMAT(1H0,≠ STATOR WAKE≠)
      N=N+1
      ALFA=ALFA3
      DWAKEM=0.0
      IF(AMWAKS.GT.0.0) GO TO 632
      GO TO 633
  632 CALL WICWAK(RHOG(2),V2,DWAKE,DWAKEM)
  633 D1=DWAKEM
      IF(D1.LT.0.0) D1=0.0
      IF(D1.GT.DIN) D1=DIN
      AMING1=AMWAKS
      ALFA=ALFA3
      SDELV1=DELVU2
      DWAKEM=0.0
      IF(BMWAKS.GT.0.0) GO TO 6330
      GO TO 6331
 6330 CALL WICWAK(RHOG(2),SDELV1,DWAKE,DWAKEM)
 6331 D2=DWAKEM
      IF(D2.LT.0.0) D2=0.0
      IF(D2.GT.DDIN) D2=DDIN
      SUP2=(90.0-ALFA3)/180.0
      AMING2=BMWAKS*SUP2
      SDELV2=DELVL2
      DWAKEM=0.0
      IF(BMWAKS.GT.0.0) GO TO 6332
      GO TO 6333
 6332 CALL WICWAK(RHOG(2),SDELV2,DWAKE,DWAKEM)
 6333 D3=DWAKEM
      IF(D3.LT.0.0) D3=0.0
      IF(D3.GT.DDIN) D3=DDIN
      SLOW2=(90.0+ALFA3)/180.0
      AMING3=BMWAKS*SLOW2
      WMASSS=WMASS(2)-AMWAKS
      WMASSL=WWMASS(2)-BMWAKS
      IF(WMASSS.LT.0.0) WMASSS=0.0
      IF(WMASSL.LT.0.0) WMASSL=0.0
      CALL WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DDAVE(2),DAVE(
     $2),D1,D2,D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)
      WWMASS(3)=AMLGE
      WMASS(3)=AMSLL
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0
      IF(WWMASS(3).LT.0.0) WWMASS(3)=0.0
      WTMASS(3)=WWMASS(2)+WMASS(2)
      VMASS(3)=VMASS(2)
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)
      TMASS(3)=MMASS
      GMASS(3)=TMASS(3)-WTMASS(3)
      DAVE(N)=DSLL
```

```
      DDAVE(N)=DLGE                                                     MAIN
      XW(3)=WMASS(3)/MMASS                                              MAIN
      XWW(3)=WWMASS(3)/MMASS                                            MAIN
      XWT(3)=WTMASS(3)/MMASS                                            MAIN
      XV(3)=XV(2)                                                       MAIN
      XA=AMASS/MMASS                                                    MAIN
      XCH4=CHMASS/MMASS                                                 MAIN
      XG=XA+XV(3)+XCH4                                                  MAIN
      XAIR(3)=XA                                                        MAIN
      XMETAN(3)=XCH4                                                    MAIN
      XGAS(3)=XG                                                        MAIN
      IF(WMASSO.LT.1.0E-6) WMASSO=WMASS(3)                              MAIN
      IF(WWMASO.LT.1.0E-6) WWMASO=WWMASS(3)                             MAIN
      IF(WTMASS(3).GT.0.0) RW=WMASS(3)/WTMASS(3)                        MAIN
      IF(WTMASS(3).GT.0.0) RWW=WWMASS(3)/WTMASS(3)                      MAIN
      TG(3)=TG(2)                                                       MAIN
      TW(3)=TW(2)                                                       MAIN
      IF(IPRINT.EQ.2) WRITE(6,619) RHOA(2),VZ,ALFA,D1,D2,WWMASS(3)      MAIN
     $,WMASS(3),VMASS(3),XW(3),XV(3)                                    MAIN
  619 FORMAT(1H ,10(F12.5,1X))                                          MAIN
      IF(IPRINT.EQ.2) WRITE(6,620) DAVE(N),TG(3),TW(3)                  MAIN
  620 FORMAT(1H ,3(F12.5,1X))                                           MAIN
      IF(WMASS(2).GT.0.0.AND.WWMASS(2).GT.0.0) GO TO 951                MAIN
      IF(WMASS(2).GT.0.0) GO TO 951                                     MAIN
      IF(WWMASS(2).GT.0.0) GO TO 951                                    MAIN
      WS(3)=WS(2)                                                       MAIN
      TB(3)=TB(2)                                                       MAIN
      TDEW(3)=TDEW(2)                                                   MAIN
      DELTG2=0.0                                                        MAIN
      DELTG3=0.0                                                        MAIN
      DELTW2=0.0                                                        MAIN
      TRATIO=TG(3)/TG(1)                                                MAIN
      DAVE(N)=0.0                                                       MAIN
      RHOA(3)=P(3)/RA/TG(3)                                             MAIN
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)        MAIN
      RHOG(3)=P(3)/RMIX/TG(3)                                           MAIN
      IF(JPERFM.NE.3) BMASS=MMASS                                       MAIN
      IF(JPERFM.EQ.3) BMASS=GMASS(3)                                    MAIN
      CALL WICMAC(ISTAGE,BMASS,TG(3),P(3),M,VZ,C,XWT(3),ALFA3,          MAIN
     $RMIX,CPMIX,AAA3)                                                  MAIN
      RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)                                 MAIN
      RHOM(3)=1.0/((1.0-XWT(3))/RHOG(3)+XWT(3)/RHOW)                    MAIN
      RHOA(3)=(1.0+G2*M**2)**G3*RHOA(3)                                 MAIN
      GO TO 950                                                         MAIN
  951 CONTINUE                                                          MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
C                                                                    C  MAIN
C CENTRIFUGAL EFFECT(IN STATOR)                                          MAIN
C                                                                    C  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
      GO TO 708                                                         MAIN
      IF(IPRINT.EQ.2) WRITE(6,8090)                                     MAIN
 8090 FORMAT(1H0,≠ CENTRIFUGAL ACTION IN STATOR≠)                       MAIN
      IF(DAVE(N-1).LT.1.0E-6) GO TO 708                                 MAIN
      DD=DAVE(N-1)                                                      MAIN
      DELZZ=SC(ISTAGE)/12.0                                             MAIN
      ALFAAV=(ALFA2+ALFA3)/2.0                                          MAIN
      IRS=1                                                             MAIN
      RHOGAS=RHOG(2)                                                    MAIN
      RHUB=SRHUB(ISTAGE)                                                MAIN
      CALL WICCEN(RZERO,UZERO,DD,VZ,DELZZ,ALFAAV,FN,IRS,RHOGAS,         MAIN
     1RHUB,R2,U2,ITIP,VZTIME,XG,XA,XV(2),XCH4,SRTIP(ISTAGE))            MAIN
      TWMAS=WMASS(2)*AREAS(ISTAGE)/AAA2                                 MAIN
      TWWMAS=WWMASS(2)*AREAS(ISTAGE)/AAA2                               MAIN
      TT=TWMAS+TWWMAS                                                   MAIN
      IF(TT.GT.0.0) TWMAS=TWMAS*WMASTL/TT                               MAIN
      IF(TT.GT.0.0) TWWMAS=TWWMAS*WMASTL/TT                             MAIN
      AMASW=WMASSO                                                      MAIN
      CALL WICDMS(IPRINT,IRAD,WMASS(2),TWMAS,AMASW,RZERO,R2,AAAIGV,     MAIN
```

```
     $RADI2(ISTAGE),SRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)
      WMASS(3)=AMASW2
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0
      IF(WMASS(3).GT.TWMAS) WMASS(3)=TWMAS
      MMASS=MMASS+DELMAS
      XW(3)=WMASS(3)/MMASS
      XWW(3)=WWMASS(3)/MMASS
      XV(3)=VMASS(3)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(3)+XCH4
      WS(3)=VMASS(3)/MMASS
      RZERO=R2
      UZERO=U2
  708 CONTINUE
      WTMASS(3)=WMASS(3)+WWMASS(3)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C HEAT TRANSFER                                                        C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C HEAT-TRANSFER (SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8120)
 8120 FORMAT(1H0,≠ HEAT TRANSFER≠)
      DELTGH=0.0
      DELTWH=0.0
      IF(DAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 8121
      GO TO 8122
 8121 RE=0.0
      XV1=(XV(1)+XV(3))/2.0
      XW1=(XW(1)+XW(3))/2.0
      WMASS1=(WMASS(1)+WMASS(3))/2.0
      VMASS1=(VMASS(1)+VMASS(3))/2.0
      CPG1=XA*WICCPA(TG(1))+XV(1)*WICCPH(TG(1))+XCH4*WICCPC(TG(1))
      CPG3=XA*WICCPA(TG(3))+XV(3)*WICCPH(TG(3))+XCH4*WICCPC(TG(3))
      CPG=(CPG1+CPG3)/2.0
      CALL WICHET(TG(1),TG(3),TW(1),TW(3),DAVE(N-2),DAVE(N)
     $,DELZ(ISTAGE),VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH
     $,DELTWH,RE)
 8122 DELTG2=DELTGH
      DELTW2=DELTWH
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C HEAT TRANSFER(LARGE DROPLET)
      DELTGH=0.0
      DELTWH=0.0
      IF(DDAVE(N-2).GT.0.0.AND.DDAVE(N).GT.0.0) GO TO 8123
      GO TO 8124
 8123 RE=0.0
      IF(DDAVE(N-1).GT.0.0) RE=REAVE
      XV1=(XV(1)+XV(3))/2.0
      XW1=(XWW(1)+XWW(3))/2.0
      WMASS1=(WWMASS(1)+WWMASS(3))/2.0
      VMASS1=(VMASS(1)+VMASS(3))/2.0
      CPG1=XA*WICCPA(TG(1))+XV(1)*WICCPH(TG(1))+XCH4*WICCPC(TG(1))
      CPG3=XA*WICCPA(TG(1))+XV(3)*WICCPH(TG(3))+XCH4*WICCPC(TG(3))
      CPG=(CPG1+CPG3)/2.0
      CALL WICHET(TG(1),TG(3),TWW(1),TWW(3),DDAVE(N-2),DDAVE(N)
     $,DELZ(ISTAGE),VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH
     $,DELTWH,RE)
 8124 DELTG3=DELTGH
      DELTW3=DELTWH
      TG(3)=TG(1)+DELTG1-DELTG2-DELTG3
      TW(3)=TW(1)+DELTW1+DELTW2
      TWW(3)=TWW(1)+DELTW3
      TRATIO=TG(3)/TG(1)
      IF(IPRINT.EQ.2) WRITE(6,627) DELTG2,DELTW2,DELTG3,DELTW3,TG(3),
     $TW(3),TWW(3),TRATIO
  627 FORMAT(1H ,8(F15.6,1X))
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C MASS-TRANCEFER
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPRINT.EQ.2) WRITE(6,8130)
 8130 FORMAT(1H0,≠ MASS TRANSFER≠)
      DAVEN2=DAVE(N-2)
      DAVEN=DAVE(N)
      DZ=DELZ(ISTAGE)
      RE=0.0
      DMDTAV=0.0
      IF(DAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 636
      GO TO 637
  636 CALL WICMAS(WS(1),TW(1),TW(3),P(1),P(3),TG(1),TG(3),DZ,PWB1,PWB2
     $,PW1,PW2,VZ,DAVEN2,DAVEN,HW2,VMASS(1),VMASS2,WMASS(1),WMASS2,
     $DMDTAV,AMASS,RE)
  637 DMDTA1=DMDTAV
      IF(DMDTA1.LT.0.0) DMDTA1=0.0
      DAVEN2=DDAVE(N-2)
      DAVEN=DDAVE(N)
      DZ=DELZ(ISTAGE)
      RE=0.0
      DMDTAV=0.0
      IF(DDAVE(N-1).GT.0.0.AND.DDAVE(N).GT.0.0) RE=REAVE
      IF(DDAVE(N-2).GT.0.0.AND.DDAVE(N).GT.0.0) GO TO 6360
      GO TO 6370
 6360 CALL WICMAS(WS(1),TWW(1),TWW(3),P(1),P(3),TG(1),TG(3),DZ,PWB1,PWB2
     $,PW1,PW2,VZ,DAVEN2,DAVEN,HW2,VMASS(1),VMASS2,WWMASS(1),WMASS2,
     $DMDTAV,AMASS,RE)
 6370 DMDTA2=DMDTAV
      IF(DMDTA2.LT.0.0) DMDTA2=0.0
      WMASS(3)=WMASS(3)-DMDTA1
      WWMASS(3)=WWMASS(3)-DMDTA2
      WMASTL=WMASTL-(DMDTA1+DMDTA2)*AAREAS(ISTAGE)/AAA2
      IF(WMASTL.LT.0.0) WMASTL=0.0
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0
      IF(WWMASS(3).LT.0.0) WWMASS(3)=0.0
      WTMASS(3)=WMASS(3)+WWMASS(3)
      VMASS(3)=VMASS(3)+DMDTA1+DMDTA2
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)
      TMASS(3)=MMASS
      GMASS(3)=TMASS(3)-WTMASS(3)
      XW(3)=WMASS(3)/MMASS
      XWW(3)=WWMASS(3)/MMASS
      XWT(3)=WTMASS(3)/MMASS
      XV(3)=VMASS(3)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(3)+XCH4
      XAIR(3)=XA
      XMETAN(3)=XCH4
      XGAS(3)=XG
      WS(3)=VMASS(3)/AMASS
      PW=WS(3)*P(3)/(WS(3)+0.6219)
      TDEW(3)=WICBPT(TG(3),PW)
      RHOA(3)=P(3)/RA/TG(3)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      RHOG(3)=P(3)/RMIX/TG(3)
      IF(JPERFM.NE.3) BMASS=MMASS
      IF(JPERFM.EQ.3) BMASS=GMASS(3)
      CALL WICMAC(ISTAGE,BMASS,TG(3),P(3),M,VZ,C,XWT(3),ALFA3,
     $RMIX,CPMIX,AAA3)
      RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)
      RHOM(3)=1.0/((1.0-XWT(3))/RHOG(3)+XWT(3)/RHOW)
      RHOA(3)=(1.0+G2*M**2)**G3*RHOG(3)
      TB(3)=WICBPT(TG(3),P(3))
      IF(IPRINT.EQ.2) WRITE(6,624) WWMASS(3),XWW(3),DDAVE(N),WMASS(3),
     $VMASS(3),XW(3),XV(3),WS(3),DAVE(N)
  624 FORMAT(1H ,9(F12.5,1X))
```

```
      IF(IPRINT.EQ.2) WRITE(6,625) RHOA(3),RHOM(3),RHOG(3),DMDTA1,DMD
     $TA2,PW2,TW(3),TG(3)
  625 FORMAT(1H ,8(F12.5,1X))
  950 DELTGW=DELTG1
      DELTDW=DELTW1
      DELTGH=-DELTG2-DELTG3
      DELTDH=DELTW2
      DELP=P(3)-P(1)
      GAMMAO=GAMMA
      TB(3)=WICBPT(TG(3),P(3))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C OUTPUT(STAGE PERFORMANCE)
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      WRITE(6,400) FAIO,ISTAGE
  400 FORMAT(1H1,1X,≠********************  ≠,1X,
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F5.3,1X,≠(ISTAGE= ≠,I2,1X,
     $≠)≠,2X,≠*********************≠)
      PRATIO=P(3)/P(1)
      TRATIO=TG(3)/TG(1)
      GAMMAV=(GAMMAS+GAMMAO)/2.0
      G4=(GAMMAV-1.0)/GAMMAV
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)
      WRITE(6,402) JPERFM
  402 FORMAT(1H0,5X,≠STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT≠,
     $≠(JPERFM=≠,I1,≠)≠)
      WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)
      WRITE(6,4025)
 4025 FORMAT(1H0,12X,≠**STAGE INLET**≠,4X,≠**STAGE OUTLET**≠,
     $4X,≠**STAGE OUTLET**≠)
      WRITE(6,4026)
 4026 FORMAT(1H ,33X,≠(BEFORE INTER-≠,6X,≠(AFTER INTER-≠)
      WRITE(6,4027)
 4027 FORMAT(1H ,34X,≠STAGE ADJUST-≠,7X,≠STAGE ADJUST-≠)
      WRITE(6,4028)
 4028 FORMAT(1H ,34X,≠MENT)≠,15X,≠MENT)≠)
      WRITE(6,405) XV(1), XV(1), XV(3)
  405 FORMAT(1H ,5X,≠XV=≠,3(F15.5,5X))
      WRITE(6,406) XW(1), XW(1) , XW(3)
  406 FORMAT(1H ,5X,≠XW=≠,3(F15.5,5X))
      WRITE(6,4060) XWW(1),XWW(1),XWW(3)
 4060 FORMAT(1H ,5X,≠XWW=≠,3(F15.5,5X))
      WRITE(6,4061) XWT(1),XWT(1),XWT(3)
 4061 FORMAT(1H ,5X,≠XWT=≠,3(F15.5,5X))
      WRITE(6,4062) XAIR(1),XAIR(1),XAIR(3)
 4062 FORMAT(1H ,5X,≠XAIR=≠,3(F15.5,5X))
      WRITE(6,4063) XMETAN(1),XMETAN(1),XMETAN(3)
 4063 FORMAT(1H ,5X,≠XMETAN=≠,3(F15.5,5X))
      WRITE(6,4064) XGAS(1),XGAS(1),XGAS(3)
 4064 FORMAT(1H ,5X,≠XGAS≠,3(F15.5,5X))
      WRITE(6,407) WMASS(1), WMASS(1) , WMASS(3)
  407 FORMAT(1H ,5X,≠WMASS=≠,3(F15.5,5X))
      WRITE(6,4070) WWMASS(1),WWMASS(1),WWMASS(3)
 4070 FORMAT(1H ,5X,≠WWMASS=≠,3(F15.5,5X))
       WRITE(6,4071) WTMASS(1),WTMASS(1),WTMASS(3)
 4071 FORMAT(1H ,5X,≠WTMASS=≠,3(F15.5,5X))
       WRITE(6,4072) AMASS,AMASS,AMASS
 4072 FORMAT(1H ,5X,≠AMASS=≠,3(F15.5,5X))
      WRITE(6,4073) CHMASS,CHMASS,CHMASS
 4073 FORMAT(1H ,5X,≠CHMASS=≠,3(F15.5,5X))
      WRITE(6,408) VMASS(1) , VMASS(1) , VMASS(3)
  408 FORMAT(1H ,5X,≠VMASS=≠,3(F15.5,5X))
      WRITE(6,4080) GMASS(1),GMASS(1),GMASS(3)
 4080 FORMAT(1H ,5X,≠GMASS=≠,3(F15.5,5X))
      WRITE(6,4081) TMASS(1),TMASS(1),TMASS(3)
```

```
 4081 FORMAT(1H ,5X,≠TMASS=≠,3(F15.5,5X))
      WRITE(6,409) WS(1) , WS(1) , WS(3)
  409 FORMAT(1H ,5X,≠WS=≠,3(F15.5,5X))
      WRITE(6,410) RHOA(1) , RHOA(2) , RHOA(3)
  410 FORMAT(1H ,5X,≠RHOA=≠,3(F15.5,5X))
      WRITE(6,411) RHOM(1), RHOM(2),RHOM(3)
  411 FORMAT(1H ,5X,≠RHOM=≠,3(F15.5,5X))
      WRITE(6,412) RHOG(1),RHOG(2),RHOG(3)
  412 FORMAT(1H ,5X,≠RHOG=≠,3(F15.5,5X))
      WRITE(6,413) TG(1),TG(2),TG(3)
  413 FORMAT(1H ,5X,≠TG=≠,3(F15.5,5X))
      WRITE(6,414) TW(1),TW(2),TW(3)
  414 FORMAT(1H ,5X,≠TW=≠,3(F15.5,5X))
      WRITE(6,4140) TWW(1),TWW(2),TWW(3)
 4140 FORMAT(1H ,5X,≠TWW=≠,3(F15.5,5X))
      WRITE(6,415) P(1),P(2),P(3)
  415 FORMAT(1H ,5X,≠P=≠,3(F15.5,5X))
      WRITE(6,416) TB(1),TB(2),TB(3)
  416 FORMAT(1H ,5X,≠TB=≠,3(F15.5,5X))
      WRITE(6,422) TDEW(1),TDEW(2),TDEW(3)
  422 FORMAT(1H ,5X,≠TDEW=≠,3(F15.5,5X))
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C BOILING
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      GO TO 450
      IF(XDIN.GT.0.0) GO TO 460
      GO TO 450
  460 IF(TW(3).LT.TB(3)) GO TO 450
      HV=1115.3272-0.6840909*(TB(3)-460.0)
      DAMY=CPG/HV*(TG(3)-TB(3))
      XE=DAMY/(DAMY+1.0)
      IF(XE.GT.XW(3)) GO TO 451
      XEVAPO=XE
      TW(3)=TB(3)
      TG(3)=TB(3)
      XW(3)=XW(3)-XEVAPO
      XV(3)=XV(3)+XEVAPO
      GO TO 452
  451 XEVAPO=XW(3)
      TW(3)=0.0
      TG(3)=TG(3)-XW(3)/(1.0-XW(3))*HV/CPG
      XW(3)=0.0
      XV(3)=XV(3)+XEVAPO
  452 WMASS(3)=XW(3)*MMASS
      VMASS(3)=XV(3)*MMASS
      GMASS(3)=VMASS(3)+AMASS
      IF(IPRINT.EQ.2) WRITE(6,453)
  453 FORMAT(1H0,≠BOILING≠)
      IF(IPRINT.EQ.2) WRITE(6,454) HV,XEVAPO,TW(3),TG(3),XW(3),XV(3)
     $,WMASS(3),GMASS,VMASS(3),MMASS
  454 FORMAT(1H0,10(F10.5,2X))
  450 CONTINUE
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C BLEED
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(XBLEED(ISTAGE).GT.0.0) GO TO 456
      GO TO 455
  456 CONTINUE
      XB=1.0-XBLEED(ISTAGE)
      AMASS=AMASS*XB
      CHMASS=CHMASS*XB
      VMASS(3)=VMASS(3)*XB
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)
      TMASS(3)=MMASS
```

```
      GMASS(3)=TMASS(3)-WTMASS(3)
      XW(3)=WMASS(3)/MMASS
      XWW(3)=WWMASS(3)/MMASS
      XWT(3)=WTMASS(3)/MMASS
      XV(3)=VMASS(3)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(3)+XCH4
      XAIR(3)=XA
      XMETAN(3)=XCH4
      XGAS(3)=XG
  455 CONTINUE
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C REPEAT
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(ISTAGE.EQ.NS) GO TO 902
      GO TO 900
  902 OVALPR=P(3)/OP01
      OVALTR=TG(3)/OT01G
      GAMMAV=(GAMMAI+GAMMAO)/2.0
      G4=(GAMMAV-1.0)/GAMMAV
      OVALEF=(OVALPR**G4-1.0)/(OVALTR-1.0)
      ODELTG=TG(3)-OT01G
      ODELTW=0.0
      DELTWW=0.0
      DELMT=0.0
      DELMWT=0.0
      DELMG=0.0
      IF(XDIN.GT.0.0) ODELTW=TW(3)-OT01D
      IF(XDDIN.GT.0.0) DELTWW=TWW(3)-OT01D
      DELMT=(MMASS-TLMO)/TLMO
      IF(WTMO.GT.0.0) DELMWT=(WTMASS(3)-WTMO)/WTMO
      DELMG=(GMASS(3)-GMO)/GMO
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C OUTPUT (OVERALL PERFORMANCE)
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      WRITE(6,421)
  421 FORMAT(1H1,≠*********** OVERALL PERFORMANCE *********≠)
      WRITE(6,4220) FAIO
 4220 FORMAT(1H0,1X,≠INITIAL FLOW COEFFICIENT=≠,F5.2)
      WRITE(6,423) CRPM,FNF
  423 FORMAT(1H0,1X,≠CORRECTED SPEED=≠,F7.1,5X,F5.3,1X,
     $≠FRACTION OF DEIGN CORRECTED SPEED≠)
      WRITE(6,424)XDIN,XDDIN,XWTO,RHUMID,XCH4IN
  424 FORMAT(1H0,1X,≠INITIAL WATER CONTENT(SMALL DROPLET)=≠,F5.3,/,
     $2X,≠INITIAL WATER CONTENT(LARGE DROPLET)=≠,F5.3,/,
     $2X,≠INITIAL WATER CONTENT(TOTAL)=≠,F5.3,/,
     $2X,≠INITIAL RELATIVE HUMIDITY=≠,F5.1,1X,≠PER CENT≠,/,
     $2X,≠INITIAL METHANE CONTENT=≠,F5.3)
      WRITE(6,425) TOG
  425 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL TEMPERATURE=≠,F8.2)
      WRITE(6,426) PO
  426 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F8.2)
      CCMASS=CMASS*AAAR1T/AAAIGV
      C2MASS=CMASS2*AAAR1T/AAAIGV
      WRITE(6,427)  CMASS,CCMASS
  427 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE OF MIXTURE=≠,F6.3,
     $≠(≠,F6.3,≠)≠)
      WRITE(6,428)  CMASS2,C2MASS
  428 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE OF GAS PHASE ≠,F6.3,
     $≠(≠,F6.3,≠)≠)
      WRITE(6,429) OVALPR
  429 FORMAT(1H0,1X,≠OVERALL TOTAL PRESSURE RATIO=≠,F6.4)
      WRITE(6,430) OVALTR
```

```
  430 FORMAT(1H0,1X,≠OVERALL TOTAL TEMPERATURE RATIO=≠,F6.4)
      WRITE(6,431) OVALEF
  431 FORMAT(1H0,1X,≠OVERALL ADIABATIC EFFICIENCY=≠,F6.4)
      WRITE(6,432) ODELTG
  432 FORMAT(1H0,1X,≠OVERALL TEMPERATURE RISE OF GAS PHASE=≠,F8.3)
      GO TO 901
  998 STOP
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICSPC                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPC(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAV,DELV,WMAS,
     $WWMAS,N,
     $OMEGA1,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,REAVE,
     $DELVU2,DELVL2,AK1,AK2,AK3)
      REAL M,MMASS
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
     X, UTIPG(6),UTIP(6),UTIPD(6),UDU(6),UMEAN(6),UHUB(6),U(6),FAI
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      DIMENSION RHOM(3),ETAA(6)
      IPRINT=1
      CPW=1.0
      RHOW=62.3
      GC=32.174
      AJ=778.26
      PAI=3.1415926
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      RHOG(1)=P(1)/RMIX/TG(1)
      BMASS=MMASS-WMAS-WWMAS
      AAA2=AREAS(ISTAGE)
      AAA3=AREA(ISTAGE+1)
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,
     $RMIX,CPMIX,AAA1)
      ASPEED=C
      ASPED1=ASPEED
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)
      VZ1=VZ
      VZZ=VZ
      FAI1=VZ1/UTIPG(ISTAGE)
      ALFA1R = ALFA1 * PAI / 180.0
      V1 = VZ / COS ( ALFA1R )
      VS1 = VZ * TAN ( ALFA1R )
      WS1 = U(ISTAGE)- VS1
      T = WS1 / VZ
      BETA1R = ATAN ( T)
      BETA1 = BETA1R * 180.0 / PAI
      TT = VZ **2 + WS1 **2
      W1 = SQRT ( TT )
      AMACH1 = W1 / ASPEED
      AMAC1=V1/ASPEED
      TS1=TG(1)/(1.0+G2*AMAC1**2)
      PS1=(TG(1)/TS1)**(-G1)*P(1)
      PREL1=(1.0+G2*AMACH1**2)**G1*PS1
```

```
      TREL1=(1.0+G2*AMACH1**2)*TS1                                      WICSPC
      TG(2)=TG(1)                                                       WICSPC
      P(2)=P(1)                                                         WICSPC
      ALFA2=BET1SS(ISTAGE)                                              WICSPC
      JJJ=1                                                             WICSPC
 2000 VZ2AS=VZ                                                          WICSPC
      CALL WICGSL(OMEGR(ISTAGE),SIGUMR(ISTAGE),BET1SR(ISTAGE),BET2SR(   WICSPC
     $ISTAGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),AMACH1,BETA1,DEQS,DEQN,     WICSPC
     $SITACS,SITACN,BET2N,OMEGAN,FMR1(ISTAGE),IDESIN,AK1,AK2,AK3,VZ1,   WICSPC
     $VZ2AS,U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))                      WICSPC
      OMEGA7=OMEGAN                                                     WICSPC
      BETA2=BET2N                                                       WICSPC
      BETA1R=BETA1*PAI/180.0                                            WICSPC
      BETA2R=BETA2*PAI/180.0                                            WICSPC
      BETAVE=(BETA1R+BETA2R)/2.0                                        WICSPC
      TANGT=WICTAN(BETA1R)-WICTAN(BETA2R)                               WICSPC
      CSAV=COS(BETAVE)                                                  WICSPC
      CS1=COS(BETA1R)                                                   WICSPC
      CL=2.0/SIGUMR(ISTAGE)*TANGT*CSAV                                  WICSPC
      CDS=0.018*(CL**2)                                                 WICSPC
      OMEGSE=CDS*SIGUMR(ISTAGE)*(CS1**2)/(CSAV**3)                      WICSPC
      H=RRTIP(ISTAGE)-RRHUB(ISTAGE)                                     WICSPC
      SHR=RC(ISTAGE)/H/SIGUMR(ISTAGE)                                   WICSPC
      CDA=0.020*SHR                                                     WICSPC
      OMEGAN=CDA*SIGUMR(ISTAGE)*(CS1**2)/(CSAV**3)                      WICSPC
      IF(IPRINT.EQ.2) WRITE(6,2001) OMEGSE,OMEGAN,OMEGA7,CDS,CDA        WICSPC
 2001 FORMAT(1H0,5F10.6)                                                WICSPC
      OMES1=OMEGSE                                                      WICSPC
      OMEA1=OMEGAN                                                      WICSPC
      AINCIR=BETA1-BET1MR(ISTAGE)                                       WICSPC
      ADEVIR=BET2N-BET2MR(ISTAGE)                                       WICSPC
      BETA2R=BETA2*PAI/180.0                                            WICSPC
      W2=VZ/COS(BETA2R)                                                 WICSPC
      UG=(W1+W2)/2.0                                                    WICSPC
      CALL WICRSL(SIGUMR(ISTAGE),BETA1,BETA2,RC(ISTAGE),DAV,CDR,OMEGAR) WICSPC
      OMEGA1=OMEGAR*2.0                                                 WICSPC
      DELP1=OMEGA1*0.5*RHOG(1)/GC*(W1**2)                               WICSPC
      IF(IPRINT.EQ.2) WRITE(6,2002) OMEGA1,DELP1                        WICSPC
 2002 FORMAT(1H ,1X,≠OMEGA1=≠,2F10.5)                                   WICSPC
      XG=1.0-XWT(1)                                                     WICSPC
      CALL WICIRL(ISTAGE,RRTIP(ISTAGE),XWW(1),XG,RHOG(1),BETA1,W1,WW1,WW WICSPC
     $2,WW)                                                             WICSPC
      BMIMPR=WW                                                         WICSPC
      IF(BMIMPR.GT.WWMAS) BMIMPR=WWMAS                                  WICSPC
      BMREBR=BMIMPR*PREB/100.0                                          WICSPC
      BMWAKR=BMIMPR*(1.0-PREB/100.0)                                    WICSPC
      BMNOIR=WWMAS-BMIMPR                                               WICSPC
      XWWNOR=BMNOIR/MMASS                                               WICSPC
      XWWRER=BMREBR/MMASS                                               WICSPC
      XWWWAR=BMWAKR/MMASS                                               WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR, WICSPC
     $XWWRER,XWWWAR                                                     WICSPC
 6090 FORMAT(1H ,7(F12.5,1X))                                           WICSPC
      RST1=RADI1(ISTAGE)**2-AAA1*144.0/2.0/PAI                          WICSPC
      RST1=SQRT(RST1)                                                   WICSPC
      RST2=2.0*RADI1(ISTAGE)**2-RST1**2                                 WICSPC
      RST2=SQRT(RST2)                                                   WICSPC
      DELR=(RST2-RST1)/12.0                                             WICSPC
      FMASSR=BMWAKR/DELR                                                WICSPC
      CALL WICFML(W1,W2,FMASSR,RHOG(1),RC(ISTAGE),SIGUMR(ISTAGE),BETA1, WICSPC
     $BETA2,CDF,OMEGAF)                                                 WICSPC
      OMEGA2=OMEGAF                                                     WICSPC
      DELP2=OMEGA2*0.5*RHOG(1)/GC*(W1**2)                               WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6091) OMEGA2,DELP2                        WICSPC
 6091 FORMAT(1H ,1X,≠OMEGA2=≠,2F10.5)                                   WICSPC
      V2=0.0                                                            WICSPC
      V3=0.0                                                            WICSPC
      ALFA=0.0                                                          WICSPC
      ALFA3=0.0                                                         WICSPC
      CALL WICSTL(ISTAGE,1,DAV,W1,W2,DELV,V2,V3,WWMAS,VZ,N,BETA1,BETA2, WICSPC
```

```
     $ALFA2,ALFA3,BMASS,DELVU2,DELVL2,OMEGRU,OMEGRL,OMEGSU,OMEGSL,
     $DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)
      OMEGA3=OMEGRU+OMEGRL
      DELP3=OMEGA3*0.5*RHOG(1)/GC*(W1**2)
      IF(IPRINT.EQ.2) WRITE(6,6092) OMEGA3,DELP3
 6092 FORMAT(1H ,1X,≠OMEGA3=≠,2F10.5)
      REAVE1=REAVE
      BETA2R = BETA2 * PAI / 180.0
      JJ=1
  200 VZAS=VZ
      WS2 = VZ * TAN ( BETA2R )
      VS2 = UU2(ISTAGE) - WS2
      TTT=VS2/VZ
      ALFA2R = ATAN ( TTT )
      ALFA2 = ALFA2R * 180.0 / PAI
      TTTT = VZ ** 2 + WS2 ** 2
      W2 = SQRT ( TTTT )
      TTTTT = VZ ** 2 + VS2 ** 2
      V2 = SQRT ( TTTTT )
      DELH=WKDONE*(UU2(ISTAGE)*VS2-U(ISTAGE)*VS1)/GC/AJ
      CALL WICIRS(ISTAGE,RRTIP(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,
     $WW2,WW)
      AMIMPR=WW
      IF(AMIMPR.GT.WMAS) AMIMPR=WMAS
      PREB=50.0
      AMREBR=AMIMPR*PREB/100.0
      AMWAKR=AMIMPR*(1.0-PREB/100.0)
      AMNOIR=WMAS-AMIMPR
      XW1=0.0
      XW2=0.0
      XW3=0.0
      IF(WMAS.GT.0.0) XW1=AMNOIR/WMAS
      IF(WMAS.GT.0.0) XW2=AMWAKR/WMAS
      IF(WMAS.GT.0.0) XW3=AMREBR/WMAS
      DELTG=DELH/CPMIX
      DELTW1=DELH/CPW
      DELTW2=DELH/CPW
      DELTW3=0.0
      DELTW=XW1*DELTW1+XW2*DELTW2+XW3*DELTW3
      DETWW1=0.0
      DETWW2=0.0
      DETWW3=0.0
      DELTWW=0.0
      TW(2)=TW(1)+DELTW
      TWW(2)=TWW(1)+DELTWW
      TG(2)=TG(1)+DELTG
      TS2=TG(2)-V2**2/(2.0*CPMIX*GC*AJ)
      AG2=(GAMMA*RMIX*TS2*GC)**0.5
      ASPEED=WICASD(XWT(1),RHOG(1),AG2)
      ASPED2=ASPEED
      AMAC2=V2/ASPEED
      AMACH2=W2/ASPEED
      PP1=GAMMA*RMIX*TREL1*GC
      PP2=(UU2(ISTAGE)/U(ISTAGE))**2-1.0
      PP3=1.0+G2*U(ISTAGE)**2/PP1*PP2
      PP=PP3**G1
      PRREL=PP-(OMEGA7+OMEGA1+OMEGA2+OMEGA3)*(1.0-PS1/PREL1)
      PR12=(TG(2)/TG(1))**G1*PRREL
      P(2)=PR12*P(1)
      PS2=(1.0+G2*AMAC2**2)**(-G1)*P(2)
      RHOG2=PS2/RMIX/TS2
      RHOG(2)=RHOG2
      RHOM2=1.0/(XG/RHOG2+XWT(1)/RHOW)
      VZ=BMASS/RHOG2/AAA2
      VZ2=VZ
      EPS=1.0E-4
      IF(JJ.EQ.2) GO TO 201
      IF(JJ.GT.2) GO TO 202
      X1=VZAS
      Y1=VZ2
```

```
      VZ=VZ2
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  201 X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,203) JJ,VZ
  203 FORMAT(1H ,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  202 IF(ABS((VZAS-VZ2)/VZAS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,204) JJ,VZ
  204 FORMAT(1H0,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      IF(JJ.EQ.20) GO TO 999
      GO TO 200
  300 VZ2CL=VZ
      IF(JJJ.EQ.2) GO TO 2010
      IF(JJJ.GT.2) GO TO 2020
      XX1=VZ2AS
      YY1=VZ2CL
      JJJ=JJJ+1
      GO TO 2000
 2010 XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2030) JJJ,VZ
 2030 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      GO TO 2000
 2020 IF(ABS((VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 3000
      XX1=XX2
      YY1=YY2
      XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2040) JJJ,VZ
 2040 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      IF(JJJ.EQ.20) GO TO 3000
      GO TO 2000
 3000 VZ2=VZ2CL
      FAI2=VZ2/UTIPG(ISTAGE)
      P(2)=(1.0+G2*AMAC2**2)**G1*PS2
      JJJJ=1
 3001 VZ3AS=VZ
      CALL WICGSL(OMEGS(ISTAGE),SIGUMS(ISTAGE),BET1SS(ISTAGE),BET2SS
     $(ISTAGE),AINCSS(ISTAGE),ADEVSS(ISTAGE),AMAC2,ALFA2,DEQS,DEQN,
     $SITACS,SITACN,BET2N,OMEGAN,FMA2(ISTAGE),IDESIN,AK1,AK2,AK3,VZ2,
     $VZ3AS,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))
      OMEGA8=OMEGAN
      ALFA3=BET2N
      ALFA1R=ALFA2*PAI/180.0
      ALFA2R=ALFA3*PAI/180.0
      ALFAAV=(ALFA1R+ALFA2R)/2.0
      TANGT=WICTAN(ALFA1R)-WICTAN(ALFA2R)
      CSAV=COS(ALFAAV)
      CS1=COS(ALFA1R)
      CL=2.0/SIGUMS(ISTAGE)*TANGT*CSAV
      CDS=0.018*(CL**2)
      OMEGSE=CDS*SIGUMS(ISTAGE)*(CS1**2)/(CSAV**3)
      H=SRTIP(ISTAGE)-SRHUB(ISTAGE)
```

```
      SHR=SC(ISTAGE)/H/SIGUMR(ISTAGE)                                    WICSPC
      CDA=0.020*SHR                                                      WICSPC
      OMEGAN=CDA*SIGUMS(ISTAGE)*(CS1**2)/(CSAV**3)                       WICSPC
      IF(IPRINT.EQ.2) WRITE(6,3002)                                      WICSPC
     $OMEGSE,OMEGAN,OMEGA8,CDS,CDA                                       WICSPC
 3002 FORMAT(1H0,5F10.5)                                                 WICSPC
      OMES2=OMEGSE                                                       WICSPC
      OMEA2=OMEGAN                                                       WICSPC
      AINCIS=ALFA2-BET1MS(ISTAGE)                                        WICSPC
      ADEVIS=BET2N-BET2MS(ISTAGE)                                        WICSPC
      ALFA3R=ALFA3*PAI/180.0                                             WICSPC
      V3=VZ/COS(ALFA3R)                                                  WICSPC
      CALL WICRSL(SIGUMS(ISTAGE),ALFA2,ALFA3,SC(ISTAGE),DAV,CDR,OMEGAR)  WICSPC
      OMEGA4=OMEGAR*2.0                                                  WICSPC
      DELP4=OMEGA4*0.5*RHOG(2)/GC*(V2**2)                                WICSPC
      IF(IPRINT.EQ.2) WRITE(6,3003) OMEGA4,DELP4                         WICSPC
 3003 FORMAT(1H ,1X,≠OMEGA4=≠,2F10.5)                                    WICSPC
      CALL WICISL(ISTAGE,SRTIP(ISTAGE),XWW(2),XG,RHOG(2),ALFA2,V2,WW1    WICSPC
     $,WW2,WW)                                                           WICSPC
      BMIMPS=WW                                                          WICSPC
      IF(BMIMPS.GT.WWMAS) BMIMPS=WWMAS                                   WICSPC
      BMREBS=BMIMPS*PREB/100.0                                           WICSPC
      BMWAKS=BMIMPS*(1.0-PREB/100.0)                                     WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6616)                                      WICSPC
 6616 FORMAT(1H ,1X,≠IMPINS≠)                                            WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2),XA,RHOG(2),VZ,WW,BMIMPS,BM    WICSPC
     $REBS,BMWAKS                                                        WICSPC
 6617 FORMAT(1H ,8(F12.5,1X))                                            WICSPC
      RST1=RADI2(ISTAGE)**2-AAA2*144.0/2.0/PAI                           WICSPC
      RST1=SQRT(RST1)                                                    WICSPC
      RST2=2.0*RADI2(ISTAGE)**2-RST1**2                                  WICSPC
      RST2=SQRT(RST2)                                                    WICSPC
      DELR=(RST2-RST1)/12.0                                              WICSPC
      FMASSS=BMWAKS/DELR                                                 WICSPC
      CALL WICFML(V2,V3,FMASSS,RHOG2,SC(ISTAGE),SIGUMS(ISTAGE),BETA1,    WICSPC
     $BETA2,CDF,OMEGAF)                                                  WICSPC
      OMEGA5=OMEGAF                                                      WICSPC
      DELP5=OMEGA5*0.5*RHOG(2)/GC*(V2**2)                                WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6618) OMEGA5,DELP5                         WICSPC
 6618 FORMAT(1H ,1X,≠OMEGA5=≠,2F10.5)                                    WICSPC
      CALL WICSTL(ISTAGE,2,DAV,W1,W2,DELV,V2,V3,WWMAS,VZ,N,BETA1,BETA2,  WICSPC
     $ALFA2,ALFA3,BMASS,DELVU2,DELVL2,OMEGRU,OMEGRL,OMEGSU,OMEGSL,       WICSPC
     $DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)                                 WICSPC
      OMEGA6=OMEGSU+OMEGSL                                               WICSPC
      DELP6=OMEGA6*0.5*RHOG(2)/GC*(V2**2)                                WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6619) OMEGA6,DELP6                         WICSPC
 6619 FORMAT(1H ,1X,≠OMEGA6=≠,2F10.5)                                    WICSPC
      REAVE2=REAVE                                                       WICSPC
      REAVE=(REAVE1+REAVE2)*0.5                                          WICSPC
      PR23=1.0-(OMEGA8+OMEGA4+OMEGA5+OMEGA6)*(1.0-PS2/P(2))              WICSPC
      PR13=(TG(2)/TG(1))**G1*PRREL*PR23                                  WICSPC
      PR13I=(TG(2)/TG(1))**G1                                            WICSPC
      P(3)=PR13*P(1)                                                     WICSPC
      TG(3)=TG(2)                                                        WICSPC
      TS3=TG(3)-V3**2/(2.0*CPMIX*GC*AJ)                                  WICSPC
      AG3=(GAMMA*RMIX*TS3*GC)**0.5                                       WICSPC
      ASPEED=WICASD(XWT(1),RHOG(2),AG3)                                  WICSPC
      ASPED3=ASPEED                                                      WICSPC
      AMAC3=V3/ASPEED                                                    WICSPC
      PS3=(1.0+G2*AMAC3**2)**(-G1)*P(3)                                  WICSPC
      RHOG3=PS3/RMIX/TS3                                                 WICSPC
      RHOG(3)=RHOG3                                                      WICSPC
      RHOM3=1.0/(XG/RHOG3+XWT(1)/RHOW)                                   WICSPC
      VZ=BMASS/RHOG3/AAA3                                                WICSPC
      VZ3CL=VZ                                                           WICSPC
      IF(JJJJ.EQ.2) GO TO 3010                                           WICSPC
      IF(JJJJ.GT.2) GO TO 3020                                           WICSPC
      XXX1=VZ3AS                                                         WICSPC
      YYY1=VZ3CL                                                         WICSPC
      JJJJ=JJJJ+1                                                        WICSPC
```

```
      GO TO 3001
3010  XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3030) JJJJ,VZ
3030  FORMAT(1H ,1X,I2,2X,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      GO TO 3001
3020  IF(ABS((VZ3AS-VZ3CL)/VZ3AS).LT.EPS) GO TO 4000
      XXX1=XXX2
      YYY1=YYY2
      XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3040) JJJJ,VZ
3040  FORMAT(1H ,1X,I2,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      IF(JJJJ.EQ.20) GO TO 4000
      GO TO 3001
4000  VZ3=VZ3CL
      FAI3=VZ3/UTIPG(ISTAGE+1)
      TW(3)=TW(2)
      TWW(3)=TW(2)
      OMEGTR=OMEGA1+OMEGA2+OMEGA3+OMEGA7
      OMEGTS=OMEGA4+OMEGA5+OMEGA6+OMEGA8
      POMEG1=OMEGA1/OMEGTR*100.0
      POMEG2=OMEGA2/OMEGTR*100.0
      POMEG3=OMEGA3/OMEGTR*100.0
      POMEG4=OMEGA4/OMEGTS*100.0
      POMEG5=OMEGA5/OMEGTS*100.0
      POMEG6=OMEGA6/OMEGTS*100.0
      POMEG7=OMEGA7/OMEGTR*100.0
      POMEG8=OMEGA8/OMEGTS*100.0
      PRATIO=P(3)/P(1)
      TRATIO=TG(3)/TG(1)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      G4=1.0/G1
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)
      WRITE(6,404) FAIO,ISTAGE
 404  FORMAT(1H1,1X,≠********************  ≠,1X,
     $≠INITIAL FLOW COEFFICIENT-≠,1X,F5.3,1X,≠(STAGE=≠,I2,1X,
     $≠)≠,2X,≠**********************≠)
       WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)
 401  FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)
       WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)
 402  FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,
     $6X,≠ROTOR SPEED=≠,F7.2,/)
      WRITE(6,403) PR13,PR13I,PRREL,PR23
 403  FORMAT(1H ,5X,≠STAGE TOTAL PRESSURE RATIO(ACTUAL)=≠,F12.5,/,
     $6X,≠STAGE TOTAL PRESSURE RATIO(IDEAL)=≠,F12.5,/,
     $6X,≠LOSS FACTOR IN ROTOR=≠,F12.5,/,
     $6X,≠LOSS FACTOR IN STATOR=≠,F12.5,/)
      WRITE(6,405)
 405  FORMAT(1H0,24X,≠*ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*≠)
      WRITE(6,406) P(1),P(2),P(3)
 406  FORMAT(1H ,1X,≠TOTAL PRESSURE≠,10X,3(F10.4,5X))
      WRITE(6,407) PS1,PS2,PS3
 407  FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,3(F10.4,5X))
      WRITE(6,408) TG(1),TG(2),TG(3)
 408  FORMAT(1H ,1X,≠TOTAL TEMPERATURE(GAS)≠,3X,3(F10.4,5X))
      WRITE(6,409) TS1,TS2,TS3
 409  FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,3(F10.4,5X))
      WRITE(6,410) RHOG(1),RHOG2,RHOG3
 410  FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,3(F10.4,5X))
      WRITE(6,411) RHOM(1),RHOM2,RHOM3
 411  FORMAT(1H ,1X,≠STATIC DENSITY(MIXTURE)≠,1X,3(F10.4,5X))
      WRITE(6,412) VZ1,VZ2,VZ3
```

```
  412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,3(F10.4,5X))
      WRITE(6,413) V1,V2,V3
  413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,3(F10.4,5X))
      WRITE(6,414) W1,W2
  414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))
      WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)
  415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))
      WRITE(6,416) VS1,VS2
  416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))
      WRITE(6,417) WS1,WS2
  417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))
      WRITE(6,418) ASPED1,ASPED2,ASPED3
  418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,3(F10.4,5X))
      WRITE(6,419) AMAC1,AMAC2,AMAC3
  419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,3(F10.4,5X))
      WRITE(6,420) AMACH1,AMACH2
  420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))
      WRITE(6,421) FAI1,FAI2,FAI3
  421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,3(F10.4,5X))
      WRITE(6,422) AAA1,AAA2,AAA3
  422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,3(F10.4,5X))
      WRITE(6,423) ALFA1,ALFA2,ALFA3
  423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))
      WRITE(6,424) BETA1,BETA2
  424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))
      WRITE(6,425) AINCIR,AINCIS
  425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))
      WRITE(6,426) ADEVIR,ADEVIS
  426 FORMAT(1H ,1X,≠DEVIATION≠,30X,2(F10.4,5X))
  999 RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                   C
C SUBROUTINE WICMAC                                                 C
C                                                                   C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICMAC(ISTAGE,AMASSM,T01G,PRES,M,VZ,C,XW1,ALFA,
     $RMIX,CPMIX,AREA1)
      REAL M ,MA1,MC1,MA2,MC2,MANEW,MCNEW
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      GAMMA=1.0/(1.0-RMIX/CPMIX/778.0)
      G2=(GAMMA-1.0)/2.0
      G3=-1.0/(GAMMA-1.0)
      MA1=0.5
      RHOG1=PRES/RMIX/T01G
      RHOGS=(1.0+G2*MA1**2)**G3*RHOG1
      RHOW=62.4
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)
      TS=T01G/(1.0+G2*MA1**2)
      A=SQRT(GAMMA*RMIX*TS*32.174)
      C=WICASD(XW1,RHOGS,A)
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI
      ALFAR=ALFA*3.1415927/180.0
```

```
      MC1=VZ/C/COS(ALFAR)
      MA2=0.6
      RHOGS=(1.0+G2*MA2**2)**G3*RHOG1
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)
      TS=T01G/(1.0+G2*MA2**2)
      A=SQRT(GAMMA*RMIX*TS*32.174)
      C=WICASD(XW1,RHOGS,A)
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI
      MC2=VZ/C/COS(ALFAR)
      J=1
  300 MANEW=WICNEW(MA1,MC1,MA2,MC2)
      RHOGS=(1.0+G2*MANEW**2)**G3*RHOG1
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)
      TS=T01G/(1.0+G2*MANEW**2)
      A=SQRT(GAMMA*RMIX*TS*32.174)
      C=WICASD(XW1,RHOGS,A)
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI
      MCNEW=VZ/C/COS(ALFAR)
      ERROR=ABS(MANEW-MCNEW)
      ERROR=ERROR/MANEW
      EPS=1.0E-6
      IF(ERROR.LT.EPS) GO TO 200
      MA1=MA2
      MC1=MC2
      MA2=MANEW
      MC2=MCNEW
      J=J+1
      IF(J.LT.50) GO TO 300
      WRITE(6,403) ISTAGE
  403 FORMAT(1H0,≠MZ DOES NOT CONVERGE AT STAGE=≠,I1)
      GO TO 998
  200 M=MANEW
      IF(AMASSM.LT.0.001) ISTAGE=0
  998 RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICASD                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICASD ( XW , RHOG , CG )
      RHOW=62.2567
      CW = 4956.04
      SIGUMA = ( XW * RHOG ) / ( RHOW - XW * ( RHOW - RHOG ))
      A1 = ( 1.0-SIGUMA ) * RHOG + SIGUMA * RHOW
      A2 = ( 1.0- SIGUMA ) / ( RHOG * CG* CG )
      A3 = SIGUMA / ( RHOW * CW* CW)
      A4 = A1 * ( A2 + A3)
      WICASD = 1.0/ SQRT ( A4 )
      RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICBOA                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICBOA(OMEGAS,SIGUMA,BET1S,BET2S,AINCIS,ADEVIS,AMACH1,
     1BET1,DEQS,DEQN,SITACS,SITACN,BET2N,X,AK1,AK3,VZ1,VZ2,UR1,R1,R2)
      CALL WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,OMEGAS,
     $DEQS,SITACS)
      AINCI=BET1+AINCIS-BET1S
      BET2A=BET2S
      X1=BET2A
      DELDEQ=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X1,SIGUMA,AINCIS,AINCI)
```

```
     $-DEQS                                                             WICBOA
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1                 WICBOA
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1                      WICBOA
      BET2C=BET2S-ADEVIS+ADEVI                                          WICBOA
      Y1=BET2C                                                          WICBOA
      N=1                                                               WICBOA
   12 IF(N.GT.1) GO TO 10                                               WICBOA
      BET2A=BET2S*1.1                                                   WICBOA
   10 X2=BET2A                                                          WICBOA
      DEQN=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X2,SIGUMA,AINCIS,AINCI)     WICBOA
      DELDEQ=DEQN-DEQS                                                  WICBOA
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1                 WICBOA
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1                      WICBOA
      BET2C=BET2S-ADEVIS+ADEVI                                          WICBOA
      Y2=BET2C                                                          WICBOA
      DELBET=ABS((X2-Y2)/X2)                                            WICBOA
      EPS=1.0E-6                                                        WICBOA
      IF(DELBET.LE.EPS) GO TO 11                                        WICBOA
      BET2A=WICNEW(X1,Y1,X2,Y2)                                         WICBOA
      X1=X2                                                             WICBOA
      Y1=Y2                                                             WICBOA
      N=N+1                                                             WICBOA
      IF(N.GT.50) GO TO 13                                              WICBOA
      GO TO 12                                                          WICBOA
   11 BET2N=X2                                                          WICBOA
      GO TO 15                                                          WICBOA
   13 WRITE(6,201)                                                      WICBOA
  201 FORMAT(1H0,≠DO NOT CONVERGE≠)                                     WICBOA
   15 RETURN                                                            WICBOA
      END                                                               WICBOA
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICEDD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICEDD
C                                                                     C WICEDD
C SUBROUTINE WICEDD                                                   C WICEDD
C                                                                     C WICEDD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICEDD
      SUBROUTINE WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,       WICEDD
     $OMEGAS,DEQS,SITACS)                                               WICEDD
      C1=180.0/3.1415926                                                WICEDD
      BET1SR=BET1S/C1                                                   WICEDD
      BET2SR=BET2S/C1                                                   WICEDD
      CSB1=COS(BET1SR)                                                  WICEDD
      CSB2=COS(BET2SR)                                                  WICEDD
      CSCS=CSB2/CSB1*(VZ1/VZ2)                                          WICEDD
      CSCSS=CSB2/CSB1                                                   WICEDD
      TNB1=WICTAN(BET1SR)                                               WICEDD
      TNB2=WICTAN(BET2SR)*(VZ2/VZ1)*(R2/R1)                             WICEDD
      TNTN=TNB1-TNB2-(UR1/VZ1)*(1.0-(R2/R1)**2)                         WICEDD
      DEQS=1.12*CSCS+0.61*(CSB1**2)/SIGUMA*TNTN*CSCS                    WICEDD
      DEQS=AK3*DEQS                                                     WICEDD
      SITACS=OMEGAS*CSB2/2.0/SIGUMA*(CSCSS**2)                          WICEDD
      RETURN                                                            WICEDD
      END                                                               WICEDD
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICED
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICED
C                                                                     C WICED
C FUNCTION WICED                                                      C WICED
C                                                                     C WICED
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICED
      FUNCTION WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,BET2,SIGUMA,AINCIS,     WICED
     $AINCI)                                                            WICED
      C1=180.0/3.1415926                                                WICED
      BET1R=BET1/C1                                                     WICED
      BET2R=BET2/C1                                                     WICED
      CSB1=COS(BET1R)                                                   WICED
      CSB2=COS(BET2R)                                                   WICED
      CSCS=CSB2/CSB1*(VZ1/VZ2)                                          WICED
      TNB1=WICTAN(BET1R)                                                WICED
      TNB2=WICTAN(BET2R)*(VZ2/VZ1)*(R2/R1)                              WICED
      TNTN=TNB1-TNB2-(UR1/VZ1)*(1.0-(R2/R1)**2)                         WICED
```

```
      DEQ1=1.12*CSCS                                                    WICED
      AAA=ABS(AINCI-AINCIS)                                             WICED
      DEQ2=0.0117*(AAA**1.43)*CSCS                                      WICED
      DEQ3=0.61*(CSB1**2)/SIGUMA*TNTN*CSCS                              WICED
      WICED=DEQ1+DEQ2+DEQ3                                              WICED
      WICED=AK3*WICED                                                   WICED
      RETURN                                                            WICED
      END                                                               WICED
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICMTK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTK
C                                                                      C WICMTK
C FUNCTION WICMTK                                                      C WICMTK
C                                                                      C WICMTK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTK
      FUNCTION WICMTK(SITACS,AMACH1,DELDEQ,AK2)                          WICMTK
      IF(DELDEQ.LT.0.0) GO TO 10                                        WICMTK
      A1=0.827*AMACH1                                                   WICMTK
      A2=2.692*(AMACH1**2)                                              WICMTK
      A3=2.675*(AMACH1**3)                                              WICMTK
      A=A1-A2+A3                                                        WICMTK
      WICMTK=SITACS+A*(DELDEQ**2)*AK2                                   WICMTK
      GO TO 11                                                          WICMTK
   10 B1=2.80*AMACH1                                                    WICMTK
      B2=8.71*(AMACH1**2)                                               WICMTK
      B3=9.36*(AMACH1**3)                                               WICMTK
      B=B1-B2+B3                                                        WICMTK
      WICMTK=SITACS+B*(DELDEQ**2)*AK2                                   WICMTK
   11 RETURN                                                            WICMTK
      END                                                               WICMTK
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICLOS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICLOS
C                                                                      C WICLOS
C FUNCTION WICLOS                                                      C WICLOS
C                                                                      C WICLOS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICLOS
      FUNCTION WICLOS(BET1,BET2,SIGUMA,SITA)                            WICLOS
      C1=180.0/3.1415926                                                WICLOS
      BET1R=BET1/C1                                                     WICLOS
      BET2R=BET2/C1                                                     WICLOS
      CSB1=COS(BET1R)                                                   WICLOS
      CSB2=COS(BET2R)                                                   WICLOS
      CSCS=CSB1/CSB2                                                    WICLOS
      WICLOS=SITA*2.0*SIGUMA/CSB2*(CSCS**2)                             WICLOS
      RETURN                                                            WICLOS
      END                                                               WICLOS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICIRS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRS
C                                                                      C WICIRS
C SUBROUTINE WICIRS                                                    C WICIRS
C                                                                      C WICIRS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRS
      SUBROUTINE WICIRS(ISTAGE,R,XW1,XG,RHOG1,BETA1,W1,                 WICIRS
     1WW1 , WW2 , WW )                                                  WICIRS
      REAL LWC                                                          WICIRS
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW         WICIRS
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)        WICIRS
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)       WICIRS
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                               WICIRS
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                        WICIRS
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                        WICIRS
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)       WICIRS
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)       WICIRS
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI      WICIRS
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT      WICIRS
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                          WICIRS
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                      WICIRS
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)            WICIRS
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                  WICIRS
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)       WICIRS
      N = ISTAGE                                                        WICIRS
```

```
      PAI = 3.1415926                                                   WICIRS
      B1 = 1.0                                                          WICIRS
      B2R = ( 90.0 - BETA1 + STAGER ( N )) * PAI / 180.0                WICIRS
      B2 = COS ( B2R )                                                  WICIRS
      LWC=XW1/XG*RHOG1                                                  WICIRS
      DS1=0.07*RC(N)                                                    WICIRS
      BETA1R = BETA1* PAI / 180.0                                       WICIRS
      DS2 = 2.0 * PAI * R / RBLADE(N) * COS (BETA1R) /                  WICIRS
     $COS(B2R)                                                          WICIRS
      IF(DS2.GE.RC(N)) DS2=RC(N)                                        WICIRS
      H=(AAA1*144.0)/(2.0*PAI*R)                                        WICIRS
      A1=DS1*H*RBLADE(N)/144.0                                          WICIRS
      A2=DS2*H*RBLADE(N)/144.0                                          WICIRS
      WW1 = LWC * W1 * B1 * A1                                          WICIRS
      WW2 = LWC * W1 * B2 * A2                                          WICIRS
      WW = WW1 + WW2                                                    WICIRS
      RETURN                                                            WICIRS
      END                                                               WICIRS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICIRL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRL
C                                                                     C WICIRL
C SUBROUTINE WICIRL                                                   C WICIRL
C                                                                     C WICIRL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRL
      SUBROUTINE WICIRL(ISTAGE,R,XW1,XG,RHOG1,BETA1,W1,                 WICIRL
     1WW1 , WW2 , WW )                                                  WICIRL
      REAL LWC                                                          WICIRL
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW         WICIRL
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)        WICIRL
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)       WICIRL
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                               WICIRL
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                        WICIRL
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                        WICIRL
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)       WICIRL
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)       WICIRL
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI      WICIRL
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT      WICIRL
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                          WICIRL
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                      WICIRL
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)            WICIRL
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                  WICIRL
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)       WICIRL
      N = ISTAGE                                                        WICIRL
      PAI = 3.1415926                                                   WICIRL
      LWC=XW1/XG/RHOG1                                                  WICIRL
      ALFA=(90.0-BETA1)/2.0*PAI/180.0                                   WICIRL
      BETA=(90.0+BETA1)/2.0*PAI/180.0                                   WICIRL
      B1=SIN(ALFA)                                                      WICIRL
      B2=SIN(BETA)                                                      WICIRL
      V1=W1*COS(ALFA)                                                   WICIRL
      V2=W1*COS(BETA)                                                   WICIRL
      S=2.0*PAI*RRTIP(ISTAGE)/RBLADE(ISTAGE)/2.0                        WICIRL
      GSI=BETA1+(90.0-BETA1)/2.0                                        WICIRL
      GSIR=GSI*PAI/180.0                                                WICIRL
      STAGR=STAGER(ISTAGE)*PAI/180.0                                    WICIRL
      Y2=GAPR(ISTAGE)/2.0*(WICTAN(STAGR)-WICTAN(GSIR))+S                WICIRL
      DAMY1=(90.0-GSI)*PAI/180.0                                        WICIRL
      Y1=Y2*SIN(DAMY1)                                                  WICIRL
      DAMY2=(GSI-STAGER(ISTAGE))*PAI/180.0                              WICIRL
      DS1=Y1/SIN(DAMY2)                                                 WICIRL
      IF(DS1.GT.RC(ISTAGE)) DS1=RC(ISTAGE)                              WICIRL
      DAMY3=(90.-(90.0+BETA1)/2.0)*PAI/180.0                            WICIRL
      DAMY4=STAGER(ISTAGE)*PAI/180.0                                    WICIRL
      DAMY5=BETA1*PAI/180.0                                             WICIRL
      DAMY6=S-GAPR(ISTAGE)/2.0*(WICTAN(DAMY5)-WICTAN(DAMY3))            WICIRL
      DAMY7=COS(DAMY4)*WICTAN(DAMY3)+SIN(DAMY4)                         WICIRL
      DS2=DAMY6/DAMY7                                                   WICIRL
      IF(DS2.GT.RC(ISTAGE)) DS2=RC(ISTAGE)                              WICIRL
      H=(AAA1*144.0)/(2.0*PAI*R)                                        WICIRL
      A1=DS1*H*RBLADE(N)/144.0                                          WICIRL
```

```
      A2=DS2*H*RBLADE(N)/144.0                                          WICIRL
      WW1 = LWC * V1 * B1 * A1                                          WICIRL
      WW2 = LWC * V2 * B2 * A2                                          WICIRL
      WW = WW1 + WW2                                                    WICIRL
      RETURN                                                            WICIRL
      END                                                               WICIRL
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICISS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISS
C                                                                      C WICISS
C SUBROUTINE WICISS                                                    C WICISS
C                                                                      C WICISS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISS
      SUBROUTINE WICISS( ISTAGE ,R ,XW1, XG , RHOGAS ,ALFA2,V1 ,        WICISS
     $WW1,WW2,WW)                                                       WICISS
      REAL LWC                                                          WICISS
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW         WICISS
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)        WICISS
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)       WICISS
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                               WICISS
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                        WICISS
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                        WICISS
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)       WICISS
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)       WICISS
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI      WICISS
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT      WICISS
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                          WICISS
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                      WICISS
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)            WICISS
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                  WICISS
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)       WICISS
      LWC = XW1/ XG * RHOGAS                                            WICISS
      DS1=( 0.06 * SC ( ISTAGE ) ) / 12.0                               WICISS
      PAI=3.1415926                                                     WICISS
      B1=1.0                                                            WICISS
      B2R=(90.0-ALFA2+STAGES(ISTAGE))*PAI/180.0                         WICISS
      B2=COS(B2R)                                                       WICISS
      ALFA2R=ALFA2*PAI/180.0                                            WICISS
      DS2=2.0*PAI*R/SBLADE(ISTAGE)*COS(ALFA2R)/COS(B2R)                 WICISS
      IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE)                              WICISS
      H=(AAA2*144.0)/(2.0*PAI*R)                                        WICISS
      A1=DS1*H*SBLADE(ISTAGE)/144.0                                     WICISS
      A2=DS2*H*SBLADE(ISTAGE)/144.0                                     WICISS
      WW1=LWC*V1*B1*A1                                                  WICISS
      WW2=LWC*V1*B2*A2                                                  WICISS
      WW=WW1+WW2                                                        WICISS
      RETURN                                                            WICISS
      END                                                               WICISS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICISL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISL
C                                                                      C WICISL
C SUBROUTINE WICISL                                                    C WICISL
C                                                                      C WICISL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICISL
      SUBROUTINE WICISL(ISTAGE,R,XW1,XG,RHOG1,ALFA2,W1,WW1,WW2,WW)      WICISL
      REAL LWC                                                          WICISL
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW         WICISL
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)        WICISL
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)       WICISL
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                               WICISL
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                        WICISL
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                        WICISL
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)       WICISL
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)       WICISL
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI      WICISL
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT      WICISL
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                          WICISL
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                      WICISL
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)            WICISL
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                  WICISL
```

```
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)        WICISL
      PAI=3.1415926                                                      WICISL
      LWC = XW1/ XG * RHOG1                                              WICISL
      ALFA=(90.0-ALFA2)/2.0*PAI/180.0                                    WICISL
      BETA=(90.0+ALFA2)/2.0*PAI/180.0                                    WICISL
      B1=SIN(ALFA)                                                       WICISL
      B2=SIN(BETA)                                                       WICISL
      V1=W1*COS(ALFA)                                                    WICISL
      V2=W1*COS(BETA)                                                    WICISL
      S=2.0*PAI*SRTIP(ISTAGE)/SBLADE(ISTAGE)/2.0                         WICISL
      GSI=ALFA2+(90.0-ALFA2)/2.0                                         WICISL
      GSIR=GSI*PAI/180.0                                                 WICISL
      STAGR=STAGES(ISTAGE)*PAI/180.0                                     WICISL
      Y2=GAPS(ISTAGE)/2.0*(WICTAN(STAGR)-WICTAN(GSIR))+S                 WICISL
      DAMY1=(90.0-GSI)*PAI/180.0                                         WICISL
      Y1=Y2*SIN(DAMY1)                                                   WICISL
      DAMY2=(GSI-STAGES(ISTAGE))*PAI/180.0                               WICISL
      DS1=Y1/SIN(DAMY2)                                                  WICISL
      IF(DS1.GT.SC(ISTAGE)) DS1=SC(ISTAGE)                               WICISL
      DAMY3=(90.-(90.0+ALFA2)/2.0)*PAI/180.0                             WICISL
      DAMY4=STAGES(ISTAGE)*PAI/180.0                                     WICISL
      DAMY5=ALFA2*PAI/180.0                                              WICISL
      DAMY6=S-GAPS(ISTAGE)/2.0*(WICTAN(DAMY5)-WICTAN(DAMY3))             WICISL
      DAMY7=COS(DAMY4)*WICTAN(DAMY3)+SIN(DAMY4)                          WICISL
      DS2=DAMY6/DAMY7                                                    WICISL
      IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE)                               WICISL
      H=(AAA2*144.0)/(2.0*PAI*R)                                         WICISL
      A1=DS1*H*SBLADE(ISTAGE)/144.0                                      WICISL
      A2=DS2*H*SBLADE(ISTAGE)/144.0                                      WICISL
      WW1=LWC*V1*B1*A1                                                   WICISL
      WW2=LWC*V2*B2*A2                                                   WICISL
      WW=WW1+WW2                                                         WICISL
      RETURN                                                             WICISL
      END                                                                WICISL
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICWAK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICWAK
C                                                                      C WICWAK
C SUBROUTINE WICWAK                                                    C WICWAK
C                                                                      C WICWAK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICWAK
      SUBROUTINE WICWAK ( RHOG , V , DWAKE , DWAKEM )                    WICWAK
      VISCOF=1.20E-3                                                     WICWAK
      SIGUMA = 4.6534E-3                                                 WICWAK
      GC = 32.174                                                        WICWAK
      WE=21.0                                                            WICWAK
      DWAKE1 = ( WE * SIGUMA * GC ) / RHOG / V ** 2                      WICWAK
      SN=VISCOF**2/(RHOG*SIGUMA*DWAKE1*GC)                               WICWAK
      WELIMT=12.0*(1.0+SN**0.36)                                         WICWAK
      D1=WELIMT*SIGUMA*GC/(RHOG*V**2)                                    WICWAK
      WE=22.0                                                            WICWAK
      DWAKE2=(WE*SIGUMA*GC)/RHOG/V**2                                    WICWAK
      SN=VISCOF**2/(RHOG*SIGUMA*DWAKE2*GC)                               WICWAK
      WELIMT=12.0*(1.0+SN**0.36)                                         WICWAK
      D2=WELIMT*SIGUMA*GC/(RHOG*V**2)                                    WICWAK
      XXXX=WICNEW(DWAKE1,D1,DWAKE2,D2)                                   WICWAK
      SN=VISCOF**2/(RHOG*SIGUMA*XXXX*GC)                                 WICWAK
      WELIMT=12.0*(1.0+SN**0.36)                                         WICWAK
      DWAKE=WELIMT*SIGUMA*GC/(RHOG*V**2)                                 WICWAK
      DWAKEM = DWAKE / 3.2802 * 1.0E6                                    WICWAK
      RETURN                                                             WICWAK
      END                                                                WICWAK
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++     WICHET
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICHET
C                                                                      C WICHET
C SUBROUTINE WICHET                                                    C WICHET
C                                                                      C WICHET
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICHET
      SUBROUTINE WICHET(TG1,TG3,TW1,TW3,DAVEN2,DAVEN,                    WICHET
     $DELZI,VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH,DELTWH,RE)      WICHET
      DIMENSION DELHET(51)                                               WICHET
```

```
      REAL ND , KA , NU , MMASS,NU                                        WICHET
      DELTGH=0.0                                                          WICHET
      DELTWH=0.0                                                          WICHET
      IF(WMASS1.LT.1.0E-6) GO TO 11                                       WICHET
      PAI = 3.1415927                                                     WICHET
      DAVEAV=(DAVEN2+DAVEN)/2.0*1.0E-6*3.2802                             WICHET
      IF(DAVEAV.LT.1.0E-6) GO TO 11                                       WICHET
      RHOW = 62.54                                                        WICHET
      ND = WMASS1    / ( RHOW * 4.0 / 3.0 * PAI * ( DAVEAV / 2.0 ) ** 3)  WICHET
      KA = 0.015 / 3600.0                                                 WICHET
      PR=0.7                                                              WICHET
      NU=2.0+0.6*SQRT(RE)*PR**0.33                                        WICHET
      HCONVE = KA / DAVEAV * NU                                           WICHET
      J = 1                                                               WICHET
   10 DELT=((TG1-TW1)+(TG3-TW3))/2.0                                      WICHET
      DELHH = HCONVE * 4.0 * PAI * ( DAVEAV / 2 0 ) **2*DELT *            WICHET
     $ND*DELZI/VZ                                                         WICHET
      GMASS1=VMASS1+AMASS+CHMASS                                          WICHET
      DELTGH=DELHH/(GMASS1*CPG)                                           WICHET
      DELTWH=DELHH/(WMASS1*CPW)                                           WICHET
      TG3=TG3-DELTGH                                                      WICHET
      TW3=TW3+DELTWH                                                      WICHET
      DELHET(J)=DELHH                                                     WICHET
      J=J+1                                                               WICHET
      IF(J.EQ.2) GO TO 10                                                 WICHET
      EROR=ABS(DELHET(J-1)-DELHET(J-2))                                   WICHET
      EPS=0.0001                                                          WICHET
      IF(J.GT.50) GO TO 11                                                WICHET
      IF(EROR.GT.EPS) GO TO 10                                            WICHET
   11 RETURN                                                              WICHET
      END                                                                 WICHET
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICMAS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICMAS
C                                                                      C  WICMAS
C SUBROUTINE WICMAS                                                    C  WICMAS
C                                                                      C  WICMAS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICMAS
      SUBROUTINE  WICMAS( HW1 , TW1 , TW2 , PP1 , PP2 , TG1 , TG2 , DZ ,  WICMAS
     1 PWB1 , PWB2 , PW1 , PW2 , VZ , DDAVE1 , DDAVE2 , HW2 , VMASS1 ,    WICMAS
     1 VMASS2 , WMASS1 , WMASS2 , DMDTAV , AMASS ,RE)                     WICMAS
      PWB1 = WICPWB(TW1)*144.0                                            WICMAS
      PWB2 = WICPWB( TW2 )*144.0                                          WICMAS
      PW1 = ( HW1 * PP1 ) / ( HW1 + 0.6219 )                              WICMAS
      DMDT1 = WICMTR( TG1 , TW1 , PP1 , DDAVE1 , VZ , DZ , WMASS1 ,       WICMAS
     1PW1 ,RE)                                                            WICMAS
      PW2AS1 = PW1                                                        WICMAS
      DMDT2 = WICMTR( TG 2 , TW 2 , PP2 , DDAVE2 , VZ , DZ , WMASS1 ,     WICMAS
     1PW2AS1 ,RE)                                                         WICMAS
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0                                    WICMAS
      VMASS2 = VMASS1 + DMDTAV                                            WICMAS
      WMASS2 = WMASS1 - DMDTAV                                            WICMAS
      HW2=VMASS2/AMASS                                                    WICMAS
      PW2CL1 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )                           WICMAS
      PW2AS2 = PW1 * 1.05                                                 WICMAS
      DMDT2 = WICMTR( TG2 , TW2 , PP2 , DDAVE2 , VZ , DZ , WMASS2 ,       WICMAS
     1PW2AS2 ,RE)                                                         WICMAS
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0                                    WICMAS
      VMASS2 = VMASS1 + DMDTAV                                            WICMAS
      WMASS2 = WMASS1 - DMDTAV                                            WICMAS
      HW2 = VMASS2 / AMASS                                                WICMAS
      PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )                           WICMAS
    2 PW2ASN = WICNEW ( PW2AS1 , PW2CL1 , PW2AS2 , PW2CL2 )               WICMAS
      PW2AS1 = PW2AS2                                                     WICMAS
      PW2CL1 = PW2CL2                                                     WICMAS
      PW2AS2 = PW2ASN                                                     WICMAS
      DMDT2 = WICMTR( TG2 , TW2 , PP2 , DDAVE2 , VZ , DZ , WMASS2 , PW    WICMAS
     12AS2 ,RE)                                                           WICMAS
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0                                    WICMAS
      VMASS2 = VMASS1 + DMDTAV                                            WICMAS
      WMASS2 = WMASS1 - DMDTAV                                            WICMAS
```

```
      HW2 = VMASS2 / AMASS                                              WICMAS
      PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )                         WICMAS
      ERROR = ABS ( PW2AS2 - PW2CL2 )                                   WICMAS
      EPS = 0.01                                                        WICMAS
      IF ( ERROR . GT . EPS ) GO TO 2                                   WICMAS
      PW2 = PW2AS2                                                      WICMAS
      RETURN                                                            WICMAS
      END                                                               WICMAS
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICMTR
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTR
C                                                                      C WICMTR
C FUNCTION WICMTR                                                      C WICMTR
C                                                                      C WICMTR
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTR
      FUNCTION WICMTR(TTG,TTW,PPP,DAVE,VZ,DZ,MMASS,PW,RE)               WICMTR
      REAL KG , ND , MMASS                                              WICMTR
      IF(DAVE.LT.1.0E-6) WICMTR=0.0                                     WICMTR
      IF(DAVE.LT.1.0E-6) GO TO 10                                       WICMTR
      DD=DAVE*1.0E-6*3.2802                                             WICMTR
      T = ( TTG + TTW ) / 2.0                                           WICMTR
      PAI = 3.1415926                                                   WICMTR
      RHOW = 62.2567                                                    WICMTR
      RR = DD / 2.0                                                     WICMTR
      TT = T * 5.0 / 9.0                                                WICMTR
      PP = PPP * 47.880258                                              WICMTR
      DV=4.24028E-3*(TT**1.5)/PP                                        WICMTR
      SCT=0.60                                                          WICMTR
      SH=2.0+0.60*SQRT(RE)*SCT**0.33                                    WICMTR
      KG = DV / DD * SH                                                 WICMTR
      HV=1115.3279-0.6840909*(TTW-460.0)                                WICMTR
      PWBB=PW+29.0/18.0*0.45/HV*PPP*(TTG-TTW)                           WICMTR
      R = 85.78                                                         WICMTR
      ND = MMASS / ( RHOW * 4.0 / 3.0 * PAI * RR ** 3 )                 WICMTR
      WICMTR = KG * 4.0 * PAI * RR ** 2 * ( PWBB / TTW - PW / TTG ) / R WICMTR
     1 * ND * DZ / VZ                                                   WICMTR
   10 RETURN                                                            WICMTR
      END                                                               WICMTR
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++     WICPWB
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICPWB
C                                                                      C WICPWB
C FUNCTION WICPWB                                                      C WICPWB
C                                                                      C WICPWB
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICPWB
      FUNCTION WICPWB(TWB)                                              WICPWB
      TSTAG=TWB                                                         WICPWB
      TSTAGC=(TSTAG-492.0)/1.8                                          WICPWB
      IF(TSTAGC.LT.100.0) GO TO 40                                      WICPWB
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 41                  WICPWB
      A=5.45142                                                         WICPWB
      B=2010.8                                                          WICPWB
      GO TO 42                                                          WICPWB
   40 A=5.9778                                                          WICPWB
      B=2224.4                                                          WICPWB
      GO TO 42                                                          WICPWB
   41 A=5.6485                                                          WICPWB
      B=2101.1                                                          WICPWB
   42 AA=A-B/(TSTAGC+273.0)                                             WICPWB
      PS=10.0**AA                                                       WICPWB
      PS=PS/4.88247E-4                                                  WICPWB
      WICPWB=PS/144.0                                                   WICPWB
      RETURN                                                            WICPWB
      END                                                               WICPWB
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICNEW
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICNEW
C                                                                      C WICNEW
C FUNCTION WICNEW                                                      C WICNEW
C                                                                      C WICNEW
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICNEW
      FUNCTION WICNEW(X1,Y1,X2,Y2)                                      WICNEW
      T=ABS((X2-X1)/X1)                                                 WICNEW
```

```
      IF(T.LT.1.0E-6) WICNEW=(Y1+Y2)/2.0                                WICNEW
      IF(T.LT.1.0E-6) GO TO 100                                         WICNEW
      A=(Y2-Y1)/(X2-X1)                                                 WICNEW
      B=Y1-A*X1                                                         WICNEW
      WICNEW=B/(1.0-A)                                                  WICNEW
  100 RETURN                                                            WICNEW
      END                                                               WICNEW
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICBPT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICBPT
C                                                                      C WICBPT
C FUNCTION WICBPT                                                      C WICBPT
C                                                                      C WICBPT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICBPT
      FUNCTION WICBPT(TSTAG,PSTAG)                                      WICBPT
      TSTAGC=(TSTAG-492.0)/1.8                                          WICBPT
      IF(TSTAGC.LT.100.0) GO TO 20                                      WICBPT
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 21                  WICBPT
      A=5.45142                                                         WICBPT
      B=2010.8                                                          WICBPT
      GO TO 22                                                          WICBPT
   20 A=5.9778                                                          WICBPT
      B=2224.4                                                          WICBPT
      GO TO 22                                                          WICBPT
   21 A=5.6485                                                          WICBPT
      B=2101.1                                                          WICBPT
   22 PS=PSTAG*4.88247E-4                                               WICBPT
      TBOILK=B/(A-ALOG10(PS))                                           WICBPT
      WICBPT=TBOILK*1.8                                                 WICBPT
      RETURN                                                            WICBPT
      END                                                               WICBPT
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSH
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSH
C                                                                      C WICSH
C FUNCTION WICSH                                                       C WICSH
C                                                                      C WICSH
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSH
      FUNCTION WICSH(TSTAG,PSTAG)                                       WICSH
      TSTAGC=(TSTAG-492.0)/1.8                                          WICSH
      IF(TSTAGC.LT.100.0) GO TO 40                                      WICSH
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 41                  WICSH
      A=5.45142                                                         WICSH
      B=2010.8                                                          WICSH
      GO TO 42                                                          WICSH
   40 A=5.9778                                                          WICSH
      B=2224.4                                                          WICSH
      GO TO 42                                                          WICSH
   41 A=5.6485                                                          WICSH
      B=2101.1                                                          WICSH
   42 AA=A-B/(TSTAGC+273.0)                                             WICSH
      PS=10.0**AA                                                       WICSH
      PS=PS/4.88247E-4                                                  WICSH
      WICSH=0.6218847*PS/(PSTAG-PS)                                     WICSH
      RETURN                                                            WICSH
      END                                                               WICSH
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICTAN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICTAN
C                                                                      C WICTAN
C FUNCTION WICTAN                                                      C WICTAN
C                                                                      C WICTAN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICTAN
      FUNCTION WICTAN(X)                                                WICTAN
      A=COS(X)                                                          WICTAN
      B=SIN(X)                                                          WICTAN
      WICTAN=B/A                                                        WICTAN
      RETURN                                                            WICTAN
      END                                                               WICTAN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICCEN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICCEN
C                                                                      C WICCEN
C SUBROUTINE WICCEN                                                    C WICCEN
```

```
C                                                                      C  WICCEN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCEN
      SUBROUTINE WICCEN(RZERO,UZERO,DD,VZ,DELZZ,ALFAAV,FN,IRS,RHOGAS,     WICCEN
     1RHUB,R2,U2,ITIP,VZTIME,XG,XA,XVV,XCH4,RTIPIN)                       WICCEN
C IRS=1:STATOR                                                            WICCEN
C IRS=2:ROTOR                                                             WICCEN
      REAL N                                                              WICCEN
      PAI=3.1415926                                                       WICCEN
      ALFAAR=ALFAAV*PAI/180.0                                             WICCEN
      IF(DD.LT.1.0E-6) GO TO 12                                           WICCEN
      D=DD*1.0E-6*3.2802                                                  WICCEN
      RHOA=RHOGAS                                                         WICCEN
      RHOD=62.37                                                          WICCEN
      XXAA=XA/XG                                                          WICCEN
      XXVV=XVV/XG                                                         WICCEN
      XXCC=XCH4/XG                                                        WICCEN
      VISCO=(XXAA*0.05715+XXVV*0.03293+XXCC*0.035)/3600.0                 WICCEN
      ENDTIM=DELZZ/VZ                                                     WICCEN
      JJ=10                                                               WICCEN
      DELTIM=ENDTIM/FLOAT(JJ)                                             WICCEN
      R1=RZERO                                                            WICCEN
      U1=UZERO                                                            WICCEN
      TIME=0.0                                                            WICCEN
      JJJ=1                                                               WICCEN
   11 RE=D*U1/VISCO                                                       WICCEN
      B1=0.44                                                             WICCEN
      N=0.0                                                               WICCEN
      IF(RE.LT.1.9) B1=24.0                                               WICCEN
      IF(RE.LT.1.9) N=1.0                                                 WICCEN
      IF(RE.GT.1.9.AND.RE.LT.500.0) B1=18.5                               WICCEN
      IF(RE.GT.1.9.AND.RE.LT.500.0) N=0.6                                 WICCEN
      B=((VISCO**N)*B1*PAI*(RHOA**(1.0-N))*6.0)/(8.0*RHOD*PAI)            WICCEN
      C=B/(D**(1.0+N))                                                    WICCEN
      VW1=R1/12.0*2.0*PAI*FN/60.0                                         WICCEN
      IF(R1.GT.RTIPIN) VW1=RTIPIN/12.0*2.0*PAI*FN/60.0                    WICCEN
      VW2=VZ*WICTAN(ALFAAR)                                               WICCEN
      IF(ALFAAV.LT.1.0) VW=VW1                                            WICCEN
      IF(ALFAAV.GT.1.0) VW=VW1/2.0                                        WICCEN
      A=VW*VW*(1.0-RHOA/RHOD)                                             WICCEN
      DELU=(A/R1*12.0-C*U1**(2.0-N))*DELTIM                               WICCEN
      U2=U1+DELU                                                          WICCEN
      UAVE=U1+DELU/2.0                                                    WICCEN
      DELR=UAVE*DELTIM*12.0                                               WICCEN
      R2=R1+DELR                                                          WICCEN
      TIME=TIME+DELTIM                                                    WICCEN
      IPRINT=1                                                            WICCEN
      IF(IPRINT.EQ.2)                                                     WICCEN
     $WRITE(6,101) R1,VW,A,U1,DELU,U2,UAVE,DELR,R2,TIME                   WICCEN
  101 FORMAT(1H ,7(F11.4,2X),E10.4,2X,F10.4,2X,E10.4)                     WICCEN
      U1=U2                                                               WICCEN
      R1=R2                                                               WICCEN
      JJJ=JJJ+1                                                           WICCEN
      VZTIME=VZ*TIME*12.0                                                 WICCEN
      IF(TIME.GT.ENDTIM) GO TO 12                                         WICCEN
      IF(JJJ.EQ.JJ) GO TO 12                                              WICCEN
      GO TO 11                                                            WICCEN
   12 RETURN                                                              WICCEN
      END                                                                 WICCEN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICDMS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   WICDMS
C                                                                     C   WICDMS
C SUBROUTINE WICDMS                                                   C   WICDMS
C                                                                     C   WICDMS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   WICDMS
      SUBROUTINE WICDMS(IPRINT,IRAD,AMASW1,AMASWT,AMASW,R1,R2,STAREA,     WICDMS
     $RSTAVE,RTIP,DMIN,DMOUT,AMASW2,DELMAS)                               WICDMS
C     AMASW1:MASS FLOW RATE OF WATER IN A STREAM TUBE IN INTEREST         WICDMS
C     AMASWT:TOTAL MASS FLOW RATE OF WATER WHICH ENTER THE COMPRESSOR     WICDMS
C     AMASW:TOTAL MASS FLOW RATE OF WATER WHICH IS SUBJECT TO             WICDMS
C           CENTRIFUGAL FORCE                                             WICDMS
```

```
C       IRAD=1:TIP                                                      WICDMS
C       IRAD=2:MEAN                                                     WICDMS
C       IRAD=3:HUB                                                      WICDMS
        PAI=3.1415926                                                   WICDMS
        RST1=RSTAVE                                                     WICDMS
        A1=STAREA                                                       WICDMS
        A2=PAI*(R2**2-R1**2)/144.0                                      WICDMS
        A2=A2*0.5                                                       WICDMS
        DMCENT=A2/A1*AMASW                                              WICDMS
  120   IF(DMCENT.LT.0.0) DMCENT=0.0                                    WICDMS
        IF(DMCENT.GT.AMASWT) DMCENT=AMASWT                              WICDMS
        IF(R1.GT.RST1) GO TO 110                                        WICDMS
C       R1.LT.RST1                                                      WICDMS
        DMIN=DMCENT                                                     WICDMS
        DMOUT=DMCENT                                                    WICDMS
        GO TO 100                                                       WICDMS
  110   CONTINUE                                                        WICDMS
C       R1.GT.RST1                                                      WICDMS
        DMIN=0.0                                                        WICDMS
        DMOUT=DMCENT                                                    WICDMS
  100   IF(IRAD.EQ.1) DMOUT=0.0                                         WICDMS
        IF(IRAD.EQ.3) DMIN=0.0                                          WICDMS
        AMASW2=AMASW1+DMIN-DMOUT                                        WICDMS
        IF(AMASW2.LT.0.0) AMASW2=0.0                                    WICDMS
        IF(AMASW2.GT.AMASWT) AMASW2=AMASWT                              WICDMS
        DELMAS=AMASW2-AMASW1                                            WICDMS
        IF(IPRINT.EQ.2) WRITE(6,200) AMASW2,AMASW1,DMIN,DMOUT,DMCENT,   WICDMS
       $AMASWT,AMASW,DELMAS                                             WICDMS
  200   FORMAT(1H0,8(F10.5,3X))                                         WICDMS
        RETURN                                                          WICDMS
        END                                                             WICDMS
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICDML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDML
C                                                                      C WICDML
C SUBROUTINE WICDML                                                    C WICDML
C                                                                      C WICDML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDML
        SUBROUTINE WICDML(IPRINT,IRAD,AMASW1,AMASWT,AMASW,R1,R2,STAREA, WICDML
       $RSTAVE,RTIP,DMIN,DMOUT,AMASW2,DELMAS)                           WICDML
C       AMASW1:MASS FLOW RATE OF WATER IN A STREAM TUBE IN INTEREST     WICDML
C       AMASWT:TOTAL MASS FLOW RATE OF WATER WHICH ENTER THE COMPRESSOR WICDML
C       AMASW:TOTAL MASS FLOW RATE OF WATER WHICH IS SUBJECT TO         WICDML
C             CENTRIFUGAL FORCE                                         WICDML
C       IRAD=1:TIP                                                      WICDML
C       IRAD=2:MEAN                                                     WICDML
C       IRAD=3:HUB                                                      WICDML
        PAI=3.1415926                                                   WICDML
        RST1=RSTAVE                                                     WICDML
        A1=STAREA                                                       WICDML
        A2=PAI*(R2**2-R1**2)/144.0                                      WICDML
        A2=A2*0.5                                                       WICDML
        DMCENT=A2/A1*AMASW                                              WICDML
  120   IF(DMCENT.LT.0.0) DMCENT=0.0                                    WICDML
        IF(DMCENT.GT.AMASWT) DMCENT=AMASWT                              WICDML
        IF(R1.GT.RST1) GO TO 110                                        WICDML
        DMIN=DMCENT                                                     WICDML
        DMOUT=DMCENT                                                    WICDML
        GO TO 100                                                       WICDML
  110   CONTINUE                                                        WICDML
        DMIN=0.0                                                        WICDML
        DMOUT=DMCENT                                                    WICDML
  100   IF(IRAD.EQ.1) DMOUT=0.0                                         WICDML
        IF(IRAD.EQ.3) DMIN=0.0                                          WICDML
        AMASW2=AMASW1+DMIN-DMOUT                                        WICDML
        IF(AMASW2.LT.0.0) AMASW2=0.0                                    WICDML
        IF(AMASW2.GT.AMASWT) AMASW2=AMASWT                              WICDML
        DELMAS=AMASW2-AMASW1                                            WICDML
        IF(IPRINT.EQ.2) WRITE(6,200) AMASW2,AMASW1,DMIN,DMOUT,DMCENT,   WICDML
       $AMASWT,AMASW,DELMAS                                             WICDML
  200   FORMAT(1H0,8(F10.5,3X))                                         WICDML
```

```
      RETURN                                                            WICDML
      END                                                               WICDML
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICDRG
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDRG
C                                                                     C WICDRG
C SUBROUTINE WICDRG                                                    C WICDRG
C                                                                     C WICDRG
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDRG
      SUBROUTINE WICDRG(D,DELV1,RHGAS1,RHGAS2,CD2,DELV2,DRAG1,RE)       WICDRG
      REAL N,N1                                                         WICDRG
      GC=32.174                                                         WICDRG
      IPRINT=1                                                          WICDRG
      VISCOG=12.0E-6                                                    WICDRG
      PAI=3.1415927                                                     WICDRG
      IF(D.GT.0.0) GO TO 300                                            WICDRG
      CD2=0.0                                                           WICDRG
      DELV2=0.0                                                         WICDRG
      DRAG1=0.0                                                         WICDRG
      RE=0.0                                                            WICDRG
      GO TO 301                                                         WICDRG
  300 RE1=(RHGAS1*D*DELV1)/VISCOG                                       WICDRG
      RE=RE1                                                            WICDRG
      B11=0.44                                                          WICDRG
      N1=0.0                                                            WICDRG
      IF(RE.LT.1.9) B11=24.0                                            WICDRG
      IF(RE.LT.1.9) N1=1.0                                              WICDRG
      IF(RE.GT.1.9.AND.RE.LT.500.0) B11=18.5                            WICDRG
      IF(RE.GT.1.9.AND.RE.LT.500.0) N1=0.6                              WICDRG
      CD1=B11/(RE1**N1)                                                 WICDRG
      DRAG1=0.5*RHGAS1*(DELV1**2)*(PAI*D**2)*CD1                        WICDRG
     $/GC                                                               WICDRG
      DAMY=DRAG1*GC/(CD1*0.5*RHGAS2*(PAI*D**2))                         WICDRG
      IF(IPRINT.EQ.2) WRITE(6,200) D,DELV1,RHGAS1,RHGAS2,RE1,B11,N1,    WICDRG
     $CD1,DRAG1,DAMY                                                    WICDRG
  200 FORMAT(1H0,10(F10.5,2X))                                          WICDRG
      DELV2=SQRT(DAMY)                                                  WICDRG
      RE2=RHGAS2*D*DELV2/VISCOG                                         WICDRG
      B1=0.44                                                           WICDRG
      N=0.0                                                             WICDRG
      IF(RE2.LT.1.9) B1=24.0                                            WICDRG
      IF(RE2.LT.1.9) N=1.0                                              WICDRG
      IF(RE2.GT.1.9.AND.RE2.LT.500.0) B1=18.5                           WICDRG
      IF(RE2.GT.1.9.AND.RE2.LT.500.0) N=0.6                             WICDRG
      CD2=B1/(RE2**N)                                                   WICDRG
      IF(IPRINT.EQ.2) WRITE(6,101) RE1,B11,N1,CD1,DELV1,RE2,B1,N,CD2,   WICDRG
     $DELV2                                                             WICDRG
  101 FORMAT(1H0,2X,10(F10.5,2X))                                       WICDRG
      RE=(RE1+RE2)/2.0                                                  WICDRG
      IPRINT=2                                                          WICDRG
  301 RETURN                                                            WICDRG
      END                                                               WICDRG
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSIZ
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSIZ
C                                                                     C WICSIZ
C SUBROUTINE WICSIZ                                                    C WICSIZ
C                                                                     C WICSIZ
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSIZ
      SUBROUTINE WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DL,DS,D1,D2, WICSIZ
     $D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)                                  WICSIZ
      TMASS1=WMASSL+WMASSS+AMING1+AMING2+AMING3                         WICSIZ
      AML=0.0                                                           WICSIZ
      AMS=0.0                                                           WICSIZ
      IF(DL.GT.DLIMIT) AML=AML+WMASSL                                   WICSIZ
      IF(DL.LT.DLIMIT) AMS=AMS+WMASSL                                   WICSIZ
      IF(DS.GT.DLIMIT) AML=AML+WMASSS                                   WICSIZ
      IF(DS.LT.DLIMIT) AMS=AMS+WMASSS                                   WICSIZ
      IF(D1.GT.DLIMIT) AML=AML+AMING1                                   WICSIZ
      IF(D1.LT.DLIMIT) AMS=AMS+AMING1                                   WICSIZ
      IF(D2.GT.DLIMIT) AML=AML+AMING2                                   WICSIZ
      IF(D2.LT.DLIMIT) AMS=AMS+AMING2                                   WICSIZ
```

```
      IF(D3.GT.DLIMIT) AML=AML+AMING3                                   WICSIZ
      IF(D3.LT.DLIMIT) AMS=AMS+AMING3                                   WICSIZ
      TMASS2=AML+AMS                                                    WICSIZ
      ERROR=ABS(TMASS1-TMASS2)                                          WICSIZ
      IF(ERROR.LT.1.0E-6) GO TO 100                                     WICSIZ
      IF(TMASS2.LT.1.0E-6) GO TO 100                                    WICSIZ
      TT=TMASS1/TMASS2                                                  WICSIZ
      IF(TT.LT.1.0) AML=AML/TT                                          WICSIZ
      IF(TT.LT.1.0) AMS=AMS/TT                                          WICSIZ
      IF(TT.GT.1.0) AML=AML*TT                                          WICSIZ
      IF(TT.GT.1.0) AMS=AMS*TT                                          WICSIZ
  100 AMLGE=AML                                                         WICSIZ
      AMSLL=AMS                                                         WICSIZ
      ADL=0.0                                                           WICSIZ
      ADS=0.0                                                           WICSIZ
      IF(DL.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+DL*(WMASSL/AML)           WICSIZ
      IF(DL.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+DL*(WMASSL/AMS)           WICSIZ
      IF(DS.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+DS*(WMASSS/AML)           WICSIZ
      IF(DS.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+DS*(WMASSS/AMS)           WICSIZ
      IF(D1.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D1*(AMING1/AML)           WICSIZ
      IF(D1.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D1*(AMING1/AMS)           WICSIZ
      IF(D2.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D2*(AMING2/AML)           WICSIZ
      IF(D2.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D2*(AMING2/AMS)           WICSIZ
      IF(D3.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D3*(AMING3/AML)           WICSIZ
      IF(D3.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D3*(AMING3/AMS)           WICSIZ
      DLGE=ADL                                                          WICSIZ
      DSLL=ADS                                                          WICSIZ
      IF(DL.GT.0.0.AND.DLGE.GT.DL) DLGE=DL                              WICSIZ
      IF(DS.GT.0.0.AND.DSLL.GT.DS) DSLL=DS                              WICSIZ
      RETURN                                                            WICSIZ
      END                                                               WICSIZ
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICPRP
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICPRP
C                                                                     C WICPRP
C SUBROUTINE WICPRP                                                   C WICPRP
C                                                                     C WICPRP
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICPRP
      SUBROUTINE WICPRP(XAIR,XH2O,XCH4,T,RMIX,CPMIX,GAMMA,G1,G2,G3)     WICPRP
C T IN R                                                                WICPRP
C CPMIX IN BTU/LBM-R                                                    WICPRP
C RMIX IN LBF-FT/LBM-R                                                  WICPRP
      RAIR=1545.3/28.964                                                WICPRP
      RH2O=1545.3/18.016                                                WICPRP
      RCH4=1545.3/16.043                                                WICPRP
      XXAIR=XAIR/(XAIR+XH2O+XCH4)                                       WICPRP
      XXH2O=XH2O/(XAIR+XH2O+XCH4)                                       WICPRP
      XXCH4=XCH4/(XAIR+XH2O+XCH4)                                       WICPRP
      RMIX=XXAIR*RAIR+XXH2O*RH2O+XXCH4*RCH4                             WICPRP
      CPMIX=XXAIR*WICCPA(T)+XXH2O*WICCPH(T)+XXCH4*WICCPC(T)             WICPRP
      GAMMA=1.0/(1.0-RMIX/CPMIX/778.0)                                  WICPRP
      G1=GAMMA/(GAMMA-1.0)                                              WICPRP
      G2=(GAMMA-1.0)/2.0                                                WICPRP
      G3=-1.0/(GAMMA-1.0)                                               WICPRP
      RETURN                                                            WICPRP
      END                                                               WICPRP
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICCPA
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICCPA
C                                                                     C WICCPA
C FUNCTION WICCPA                                                     C WICCPA
C                                                                     C WICCPA
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICCPA
      FUNCTION WICCPA(T)                                                WICCPA
C T IN R                                                                WICCPA
C CPAIR IN BTU/LBM-R                                                    WICCPA
      TK=5.0/9.0*T                                                      WICCPA
      A=3.65359                                                         WICCPA
      B=-1.33736E-3                                                     WICCPA
      C=3.29421E-6                                                      WICCPA
      D=-1.91142E-9                                                     WICCPA
      E=0.275462E-12                                                    WICCPA
```

```
      R=8314.3/28.964
      CP=(A+B*TK+C*TK**2+D*TK**3+E*TK**4)*R
      WICCPA=CP*2.3885E-4
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICCPH                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICCPH(T)
C T IN R
C CPH2O IN BTU/LBM-R
      TK=5.0/9.0*T
      A=4.07013
      B=-1.10845E-3
      C=4.15212E-6
      D=-2.96374E-9
      E=0.807021E-12
      R=8314.3/18.016
      CP=(A+B*TK+C*TK**2+D*TK**3+E*TK**4)*R
      WICCPH=CP*2.3885E-4
      RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C FUNCTION WICCPC                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION WICCPC(T)
C T IN R
C CPCH4 IN BTU/LBM-R
      TK=5.0/9.0*T
      A=3.82619
      B=-3.97946E-3
      C=24.5583E-6
      D=-22.7329E-9
      E=6.96270E-12
      R=8314.3/16.043
      CP=(A+B*TK+C*TK**2+D*TK**3+E*TK**4)*R
      WICCPC=CP*2.3885E-4
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICGSL                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICGSL(OMEGAS,SIGUMA,BET1S,BET2S,AINCIS,ADEVIS,AMACH1,
     1BET1,DEQS,DEQN,SITACS,SITACN,BET2N,OMEGAN,X,IDESIN,AK1,AK2,AK3
     2,VZ1,VZ2,UR1,R1,R2)
      CALL WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,OMEGAS,
     $DEQS,SITACS)
      AINCI=BET1-BET1S+AINCIS
      BET2A=BET2S
      X1=BET2A
      DELDEQ=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X1,SIGUMA,AINCIS,AINCI)
     $-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      Y1=BET2C
      N=1
   12 IF(N.GT.1) GO TO 10
      BET2A=BET2S*1.1
   10 X2=BET2A
      DEQN=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X2,SIGUMA,AINCIS,AINCI)
```

```
      DELDEQ=DEQN-DEQS                                                  WICGSL
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1                 WICGSL
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1                      WICGSL
      BET2C=BET2S-ADEVIS+ADEVI                                          WICGSL
      Y2=BET2C                                                          WICGSL
      DELBET=ABS((X2-Y2)/X2)                                            WICGSL
      EPS=1.0E-6                                                        WICGSL
      IF(DELBET.LE.EPS) GO TO 11                                        WICGSL
      BET2A=WICNEW(X1,Y1,X2,Y2)                                         WICGSL
      X1=X2                                                             WICGSL
      Y1=Y2                                                             WICGSL
      N=N+1                                                             WICGSL
      IF(N.GT.50) GO TO 13                                              WICGSL
      GO TO 12                                                          WICGSL
   11 BET2N=X2                                                          WICGSL
      GO TO 14                                                          WICGSL
   13 WRITE(6,201)                                                      WICGSL
  201 FORMAT(1H0,≠DO NOT CONVERGE≠)                                     WICGSL
      GO TO 15                                                          WICGSL
   14 SITACN=WICMTK(SITACS,AMACH1,DELDEQ,AK2)                           WICGSL
      OMEGAN=WICLOS(BET1,BET2N,SIGUMA,SITACN)                           WICGSL
      SSS=SITACN-SITACS                                                 WICGSL
   15 RETURN                                                            WICGSL
      END                                                               WICGSL
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSDL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSDL
C                                                                      C WICSDL
C SUBROUTINE WICSDL                                                    C WICSDL
C                                                                      C WICSDL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSDL
      SUBROUTINE WICSDL(CHORD,SIGUMA,BETA1,BETA2,UG,RHOG,               WICSDL
     $AMASSW,AREA,VZ,IPRINT,OMEGAP)                                     WICSDL
      PAI=3.1415926                                                     WICSDL
      RHOG0=RHOG                                                        WICSDL
      RHOP0=AMASSW/AREA/VZ                                              WICSDL
      RR=RHOP0/RHOG0                                                    WICSDL
      VISCOG=0.128E-4                                                   WICSDL
      C=CHORD/12.0                                                      WICSDL
      RE=UG*C*RHOG0/VISCOG                                              WICSDL
      DELC=0.37/(RE**0.2)/(1.0+1.442*RR)**0.8                           WICSDL
      DELP=0.1402*DELC                                                  WICSDL
      BETA1R=BETA1*PAI/180.0                                            WICSDL
      BETA2R=BETA2*PAI/180.0                                            WICSDL
      OMEGAP=DELP*2.0*SIGUMA/COS(BETA2R)*(COS(BETA1R)/COS(BETA2R))**2   WICSDL
      RETURN                                                            WICSDL
      END                                                               WICSDL
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSTL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSTL
C                                                                      C WICSTL
C SUBROUTINE WICSTL                                                    C WICSTL
C                                                                      C WICSTL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSTL
      SUBROUTINE WICSTL(ISTAGE,IROTOR,DAV,W1,W2,DELV,V2,V3,WMASS,VZ,N   WICSTL
     $,BETA1,BETA2,ALFA2,ALFA3,MMASS,DELVU2,DELVL2,                     WICSTL
     $OMEGRU,OMEGRL,OMEGSU,OMEGSL,DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)    WICSTL
C IROTOR=1 ROTOR                                                        WICSTL
C IROTOR=2 STATOR                                                       WICSTL
      REAL M,MMASS                                                      WICSTL
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW         WICSTL
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)        WICSTL
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)       WICSTL
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                               WICSTL
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                        WICSTL
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                        WICSTL
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)       WICSTL
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)       WICSTL
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI      WICSTL
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT      WICSTL
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                          WICSTL
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                      WICSTL
```

```
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)           WICSTL
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                 WICSTL
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)      WICSTL
      PAI=3.1415927                                                    WICSTL
      GC=32.174                                                        WICSTL
      RHOW=62.3                                                        WICSTL
      IF(IROTOR.EQ.2) GO TO 100                                        WICSTL
C DROPLET DRAG IN ROTOR                                                WICSTL
      DD=DAV*1.0E-6*3.28                                               WICSTL
      VG1=W1                                                           WICSTL
      VP1=VG1-DELV                                                     WICSTL
      A1=WMASS*RC(ISTAGE)/12.0/VZ                                      WICSTL
      A2=RHOW*4.0/3.0*PAI*(DD/2.0)**3                                  WICSTL
      TN=0.0                                                           WICSTL
      IF(WMASS.GT.0.0) GO TO 2000                                      WICSTL
      GO TO 2001                                                       WICSTL
 2000 TN=A1/A2                                                         WICSTL
 2001 VAVE=(W1+W2)/2.0                                                 WICSTL
      GMU1=(90.0-BETA1)/2.0*PAI/180.0                                  WICSTL
      DELVU1=VG1-VP1*COS(GMU1)                                         WICSTL
      IF(N.GT.2) DELVU1=DELVU2                                         WICSTL
      TNU=TN*(180.0-BETA1-BETA2)/360.0                                 WICSTL
      XWW(2)=XWW(1)                                                    WICSTL
      XWT(2)=XWT(1)                                                    WICSTL
      CALL WICPRP(XA,XV(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)       WICSTL
      IF(IPRINT.EQ.2) WRITE(6,4000)                                    WICSTL
 4000 FORMAT(1H0,≠DROPLET DRAG IN ROTOR (UPPER PART)≠)                 WICSTL
      CALL WICDRG(DD,DELVU1,RHOG(1),RHOG(2),CD2,DELV2,DRAG1,RE)        WICSTL
      DELVU2=DELV2                                                     WICSTL
      CDRU=CD2                                                         WICSTL
      RERUP=RE                                                         WICSTL
      DRAGRU=DRAG1*TNU                                                 WICSTL
      AREA1=PAI*(RRTIP(ISTAGE)**2-RRHUB(ISTAGE)**2)/144.0/10.0         WICSTL
      DELPRU=DRAGRU/AREA1                                              WICSTL
      OMEGRU=DELPRU/(0.5*RHOG(1)/GC*W1**2)                             WICSTL
      CDRUU=CDRU*DELVU2**2*PAI/4.0*DD**2*TNU/VAVE**2/RC(ISTAGE)*12.0   WICSTL
      GML1=(90.0+BETA1)/2.0*PAI/180.0                                  WICSTL
      DELVL1=VG1-VP1*COS(GML1)                                         WICSTL
      IF(N.GT.2) DELVL1=DELVL2                                         WICSTL
      TNL=TN*(180.0+BETA1+BETA2)/360.0                                 WICSTL
      IF(IPRINT.EQ.2) WRITE(6,4001)                                    WICSTL
 4001 FORMAT(1H0,≠DROPLET DRAG IN ROTOR (LOWER PART)≠)                 WICSTL
      CALL WICDRG(DD,DELVL1,RHOG(1),RHOG(2),CD2,DELV2,DRAG1,RE)        WICSTL
      DELVL2=DELV2                                                     WICSTL
      CDRL=CD2                                                         WICSTL
      RERLOW=RE                                                        WICSTL
      DRAGRL=DRAG1*TNU                                                 WICSTL
      DELPRL=DRAGRL/AREA1                                              WICSTL
      OMEGRL=DELPRL/(0.5*RHOG(1)/GC*W1**2)                             WICSTL
      CDRLL=CDRL*DELVL2**2*PAI/4.0*DD**2*TNL/VAVE**2/RC(ISTAGE)*12.0   WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2002)                                    WICSTL
 2002 FORMAT(1H0,≠DROPLET DRAG SUMMARY≠)                               WICSTL
      IF(IPRINT.EQ.2) WRITE(6,720)DELVU1,DELVU2,DELVL1,DELVL2,CDRU,CD  WICSTL
     $RUU,CDRL,CDRLL                                                   WICSTL
     $,DRAGRU,DRAGRL                                                   WICSTL
  720 FORMAT(1H0,10(F10.5,2X))                                         WICSTL
      RUP1=(90.0-BETA1)/180.0                                          WICSTL
      RLOW1=(90.0+BETA1)/180.0                                         WICSTL
      RUP2=(90.0-BETA2)/180.0                                          WICSTL
      RLOW2=(90.0+BETA2)/180.0                                         WICSTL
      REAVE=RERUP*(RUP1+RUP2)*0.5+RERLOW*(RLOW1+RLOW2)*0.5             WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2010) RUP1,RUP2,RLOW1,RLOW2              WICSTL
 2010 FORMAT(1H0,4(F10.5,2X))                                          WICSTL
      GO TO 200                                                        WICSTL
C DROPLET DRAG IN STATOR                                               WICSTL
  100 DD=DAV*1.0E-6*3.28                                               WICSTL
      VG1=W1                                                           WICSTL
      VP1=VG1-DELV                                                     WICSTL
      A1=WMASS*SC(ISTAGE)/12.0/VZ                                      WICSTL
      A2=RHOW*4.0/3.0*PAI*(DD/2.0)**3                                  WICSTL
```

```
      TN=0.0                                                            WICSTL
      IF(WMASS.GT.0.0) GO TO 5002                                       WICSTL
      GO TO 5003                                                        WICSTL
 5002 TN=A1/A2                                                          WICSTL
 5003 VAVE=(V3+V2)/2.0                                                  WICSTL
      DELVU1=DELVU2                                                     WICSTL
      TNU=TN*(180.0-ALFA2-ALFA3)/360.0                                  WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2005)                                     WICSTL
 2005 FORMAT(1H0,≠DROPLET DRAG IN STATOR (UPPER PART)≠)                 WICSTL
      CALL WICDRG(DD,DELVU1,RHOG(2),RHOG(2),CD2,DELV2,DRAG1,RE)         WICSTL
      DELVU2=DELV2                                                      WICSTL
      CDSU=CD2                                                          WICSTL
      RESUP=RE                                                          WICSTL
      DRAGSU=DRAG1*TNU                                                  WICSTL
      AREA2=PAI*(SRTIP(ISTAGE)**2-SRHUB(ISTAGE)**2)/144.0/10.0          WICSTL
      DELPSU=DRAGSU/AREA2                                               WICSTL
      OMEGSU=DELPSU/(0.5*RHOG(2)/GC*V2**2)                              WICSTL
      CDSUU=CDSU*DELVU2**2*PAI/4.0*DD**2*TNU/VAVE**2/SC(ISTAGE)*12.0    WICSTL
      DELVL1=DELVL2                                                     WICSTL
      TNL=TN*(180.0+ALFA2+ALFA3)/360.0                                  WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2006)                                     WICSTL
 2006 FORMAT(1H0,≠DROPLET DRAG IN STATOR (LOWER PART)≠)                 WICSTL
      CALL WICDRG(DD,DELVL1,RHOG(2),RHOG(2),CD2,DELV2,DRAG1,RE)         WICSTL
      DELVL2=DELV2                                                      WICSTL
      CDSL=CD2                                                          WICSTL
      RESLOW=RE                                                         WICSTL
      DRAGSL=DRAG1*TNL                                                  WICSTL
      DELPSL=DRAGSL/AREA2                                               WICSTL
      OMEGSL=DELPSL/(0.5*RHOG(2)/GC*V2**2)                              WICSTL
      CDSLL=CDSL*DELVL2**2*PAI/4.0*DD**2*TNL/VAVE**2/SC(ISTAGE)*12.0    WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2007)                                     WICSTL
 2007 FORMAT(1H0,≠DROPLET DRAG IN STATOR (SUMMARY)≠)                    WICSTL
      IF(IPRINT.EQ.2)WRITE(6,721) DELVU1,DELVU2,DELVL1,DELVL2,CDSU,CD   WICSTL
     $SUU,CDSL,CDSLL                                                    WICSTL
     ^,DRAGSU,DRAGSL                                                    WICSTL
  721 FORMAT(1H0,10(F10.5,2X))                                          WICSTL
      SUP1=(90.0-ALFA2)/180.0                                           WICSTL
      SLOW1=(90.0+ALFA2)/180.0                                          WICSTL
      SUP2=(90.0-ALFA3)/180.0                                           WICSTL
      SLOW2=(90.0+ALFA3)/180.0                                          WICSTL
      REAVE=RESUP*(SUP1+SUP2)*0.5+RESLOW*(SLOW1+SLOW2)*0.5              WICSTL
      IF(IPRINT.EQ.2) WRITE(6,2011) SUP1,SUP2,SLOW1,SLOW2               WICSTL
 2011 FORMAT(1H0,4(F10.5,2X))                                           WICSTL
  200 RETURN                                                            WICSTL
      END                                                               WICSTL
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICFML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICFML
C                                                                      C WICFML
C SUBROUTINE WICFML                                                    C WICFML
C                                                                      C WICFML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICFML
      SUBROUTINE WICFML(WG1,WG2,FMASS,RHOG1,CHORD,SIGUMA,BETA1,BETA2,   WICFML
     $CDF,OMEGAF)                                                       WICFML
      PAI=3.1415926                                                     WICFML
      VISCOG=0.128E-4                                                   WICFML
      VISCOL=6.500E-4                                                   WICFML
      C=CHORD/12.0                                                      WICFML
      WGAVE=0.5*(WG1+WG2)                                               WICFML
      VFILM=0.5*WGAVE*VISCOG/VISCOL                                     WICFML
      CDF=FMASS*VFILM/(0.5*RHOG1*WG1*WG1*C)                             WICFML
      BETA1R=BETA1*PAI/180.0                                            WICFML
      BETA2R=BETA2*PAI/180.0                                            WICFML
      BETA3R=0.5*(BETA1R+BETA2R)                                        WICFML
      CS1=COS(BETA1R)**2                                                WICFML
      CS2=COS(BETA3R)**3                                                WICFML
      OMEGAF=CDF*SIGUMA*CS1/CS2                                         WICFML
      RETURN                                                            WICFML
      END                                                               WICFML
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICRSL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICRSL
```

```
C                                                                      C  WICRSL
C SUBROUTINE WICRSL                                                    C  WICRSL
C                                                                      C  WICRSL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICRSL
      SUBROUTINE WICRSL(SIGUMA,BETA1,BETA2,CHORD,DL,CDR,OMEGAR)           WICRSL
      PAI=3.1415926                                                       WICRSL
      IF(DL.LT.1.0E-6) CDR=0.0                                            WICRSL
      IF(DL.LT.1.0E-6) OMEGAR=0.0                                         WICRSL
      IF(DL.LT.1.0E-6) GO TO 10                                           WICRSL
      BETA1R=BETA1*PAI/180.0                                              WICRSL
      BETA2R=BETA2*PAI/180.0                                              WICRSL
      BETA3R=0.5*(BETA1R+BETA2R)                                          WICRSL
      CS1=COS(BETA1R)**2                                                  WICRSL
      CS2=COS(BETA3R)**3                                                  WICRSL
      C=CHORD*2.54*0.01*1.0E6                                             WICRSL
      A=C/DL                                                              WICRSL
      IF(A.LT.100.0) A=100.0                                              WICRSL
      CDR=1.89+1.62*ALOG10(A)                                             WICRSL
      CDR=1.0/CDR**2.5                                                    WICRSL
      OMEGAR=CDR*SIGUMA*CS1/CS2                                           WICRSL
   10 RETURN                                                              WICRSL
      END                                                                 WICRSL
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICVT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICVT
C                                                                      C  WICVT
C SUBROUTINE WICVT                                                     C  WICVT
C                                                                      C  WICVT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICVT
      SUBROUTINE WICVT(ISTAGE,ASPEED,ALFA1,VZ,V1,                         WICVT
     1VS1 , WS1 , BETA1, W1 , BETA2 , WS2 , VS2 , ALFA2 , W2 , V2 ,      WICVT
     1ALFA3 ,V3,AK1,AK3)                                                  WICVT
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW           WICVT
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)          WICVT
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)         WICVT
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                                 WICVT
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                          WICVT
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                          WICVT
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)         WICVT
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)         WICVT
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI        WICVT
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT        WICVT
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                            WICVT
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                        WICVT
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)              WICVT
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                    WICVT
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)         WICVT
      PAI = 3.1415927                                                     WICVT
      ALFA1R = ALFA1 * PAI / 180.0                                        WICVT
      V1 = VZ / COS ( ALFA1R )                                            WICVT
      VS1 = VZ * TAN ( ALFA1R )                                           WICVT
      WS1 = U(ISTAGE)- VS1                                                WICVT
      T = WS1 / VZ                                                        WICVT
      BETA1R = ATAN ( T)                                                  WICVT
      BETA1 = BETA1R * 180.0 / PAI                                        WICVT
      TT = VZ **2 + WS1 **2                                               WICVT
      W1 = SQRT ( TT )                                                    WICVT
      AMACH1 = W1 / ASPEED                                                WICVT
      CALL WICBOA (OMEGR(ISTAGE), SIGUMR ( ISTAGE ) , BET1SR ( ISTAGE     WICVT
     1),BET2SR(ISTAGE),                                                   WICVT
     1  AINCSR ( ISTAGE ) , ADEVSR ( ISTAGE ) ,                           WICVT
     1AMACH1 , BETA1 , DEQS,DEQN.SITACS,SITACN,BET2N ,FMR1(ISTAGE),       WICVT
     1AK1,AK3,VZ,VZ,U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))                WICVT
      BETA2 = BET2N                                                       WICVT
      BETA2R = BETA2 * PAI / 180.0                                        WICVT
      WS2 = VZ * TAN ( BETA2R )                                           WICVT
      VS2 = U(ISTAGE) - WS2                                               WICVT
      TTT=VS2/VZ                                                          WICVT
      ALFA2R = ATAN ( TTT )                                               WICVT
      ALFA2 = ALFA2R * 180.0 / PAI                                        WICVT
      TTTT = VZ ** 2 + WS2 ** 2                                           WICVT
```

```
      W2 = SQRT ( TTTT )                                                 WICUT
      TTTTT = VZ ** 2 + VS2 ** 2                                         WICUT
      V2 = SQRT ( TTTTT )                                                WICUT
      AMACH2 = V2 / ASPEED                                               WICUT
      CALL WICBOA (OMEGS(ISTAGE), SIGUMS(ISTAGE)  , BET1SS(ISTAGE) ,     WICUT
     1BET2SS ( ISTAGE ) , AINCSS ( ISTAGE ) , ADEVSS ( ISTAGE ),         WICUT
     1AMACH2 , ALFA2 , DEQS,DEQN,SITACS,SITACN,BET2N,FMA2(ISTAGE),       WICUT
     1AK1,AK3,VZ,VZ,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))                   WICUT
      ALFA3 = BET2N                                                      WICUT
      ALFA3R=ALFA3*PAI/180.0                                             WICUT
      V3=VZ/COS(ALFA3R)                                                  WICUT
      RETURN                                                             WICUT
      END                                                                WICUT
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSPD
C                                                                     C WICSPD
C SUBROUTINE WICSPD                                                   C WICSPD
C                                                                     C WICSPD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICSPD
      SUBROUTINE WICSPD(AMASS,ISTAGE)                                    WICSPD
      REAL M,MIN,M1,M2,M1REL,M2REL                                       WICSPD
      COMMON /PERDUE/ JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW           WICSPD
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)         WICSPD
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)        WICSPD
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                                WICSPD
     X, RRHUB(6),RC(6),RBLADE(6),STAGER(6)                               WICSPD
     X, SRHUB(7),SC(7),SBLADE(7),STAGES(7)                               WICSPD
     X, SIGUMR(6),BET1SR(6),BET2SR(6),AINCSR(6),ADEVSR(6)                WICSPD
     X, SIGUMS(7),BET1SS(7),BET2SS(7),AINCSS(7),ADEVSS(7)                WICSPD
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI       WICSPD
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT       WICSPD
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                           WICSPD
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                       WICSPD
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)             WICSPD
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                   WICSPD
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)        WICSPD
      DIMENSION TD(8)                                                    WICSPD
      AJ=778.26                                                          WICSPD
      IUNIT=1                                                            WICSPD
      CFT=1.0/1.8                                                        WICSPD
      CFP=47.880258                                                      WICSPD
      CFD=16.018463                                                      WICSPD
      CFV=0.3048                                                         WICSPD
      CFA=0.09290304                                                     WICSPD
      CFL=2.54                                                           WICSPD
      CFM=0.45359237                                                     WICSPD
      PAI=3.1415926                                                      WICSPD
      GC=32.174                                                          WICSPD
      TREF=518.70                                                        WICSPD
      PREF=14.7*144.0                                                    WICSPD
      AAAR1T=PAI*(RRTIP(1)**2-RRHUB(1)**2)/144.0*BLOCK(1)                WICSPD
      CMASS=AMASS*SQRT(TG(1)/TREF)/(P(1)/PREF)*AAAR1T/SAREA(1)           WICSPD
C IGV INLET                                                              WICSPD
      ISTAGE=NS1                                                         WICSPD
      CALL WICPRP(1.0,0.0,0.0,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)           WICSPD
      CALL WICMAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,0.0,0.0,RMIX,CPMIX,ARE  WICSPD
     $AS(NS1))                                                           WICSPD
      VZIN=VZ                                                            WICSPD
      AIN=C                                                              WICSPD
      MIN=M                                                              WICSPD
      TOIN=TG(1)                                                         WICSPD
      POIN=P(1)                                                          WICSPD
      PSIN=P(1)/(1.0+G2*M**2)**G1                                        WICSPD
      TSIN=TG(1)/(1.0+G2*M**2)                                           WICSPD
      RHOGIN=PSIN/RMIX/TSIN                                              WICSPD
      FAIIN=VZIN/UTIPG(1)                                                WICSPD
      FAID=FAIIN                                                         WICSPD
      GAMAIN=GAMMA                                                       WICSPD
      TOIN=TG(1)                                                         WICSPD
      POIN=P(1)                                                          WICSPD
```

```
C IGV INLET PRINTOUT                                                    WICSPD
      IF(IUNIT.EQ.2) THEN                                               WICSPD
      TOIN=TOIN*CFT                                                     WICSPD
      POIN=POIN*CFP                                                     WICSPD
      TSIN=TSIN*CFT                                                     WICSPD
      PSIN=PSIN*CFP                                                     WICSPD
      RHOGIN=RHOGIN*CFD                                                 WICSPD
      AIN=AIN*CFV                                                       WICSPD
      VZIN=VZIN*CFV                                                     WICSPD
      AREAS(NS1)=AREAS(NS1)*CFA                                         WICSPD
      ENDIF                                                             WICSPD
      WRITE(6,1000)                                                     WICSPD
 1000 FORMAT(1H1,≠*************** DESIGN POINT INFORMATION ************ WICSPD
     $****≠)                                                            WICSPD
      WRITE(6,1010)                                                     WICSPD
 1010 FORMAT(1H0,1X,≠***** COMPRESSOR INLET *****≠)                     WICSPD
      WRITE(6,1020) TOIN,POIN,TSIN,PSIN,RHOGIN                          WICSPD
 1020 FORMAT(1H0,1X,≠TOTAL TEMPERATURE AT COMPRESSOR INLET=≠,F10.5,/,   WICSPD
     $2X,≠TOTAL PRESSURE AT COMPRESSOR INLET=≠,F10.2,/,                 WICSPD
     $2X,≠STATIC TEMPERATURE AT COMPRESSOR INLET=≠,F10.5,/,             WICSPD
     $2X,≠STATIC PRESSURE AT COMPRESSOR INLET=≠,F10.2,/,                WICSPD
     $2X,≠STATIC DENSITY AT COMPRESSOR INLET=≠,F10.5)                   WICSPD
      WRITE(6,1030) AIN,VZIN,MIN,AREAS(NS1),FAIIN                       WICSPD
 1030 FORMAT(1H0,1X,≠ACOUSTIC SPEED AT COMPRESSOR INLET=≠,F10.5,/,      WICSPD
     $2X,≠AXIAL VELOCITY AT COMPRESSOR INLET=≠,F10.5,/,                 WICSPD
     $2X,≠MACH NUMBER AT COMPRESSOR INLET=≠,F10.5,/,                    WICSPD
     $2X,≠STREAMTUBE AREA AT COMPRESSOR INLET=≠,F10.5,/,                WICSPD
     $2X,≠FLOW COEFFICIENT AT COMPRESSOR INLET=≠,F10.5)                 WICSPD
      IF(IUNIT.EQ.2) THEN                                               WICSPD
      TOIN=TOIN/CFT                                                     WICSPD
      POIN=POIN/CFP                                                     WICSPD
      TSIN=TSIN/CFT                                                     WICSPD
      PSIN=PSIN/CFP                                                     WICSPD
      RHOGIN=RHOGIN/CFD                                                 WICSPD
      AIN=AIN/CFV                                                       WICSPD
      VZIN=VZIN/CFV                                                     WICSPD
      AREAS(NS1)=AREAS(NS1)/CFA                                         WICSPD
      ENDIF                                                             WICSPD
C ROTOR INLET                                                           WICSPD
      ISTAGE=1                                                          WICSPD
  100 I=ISTAGE-1                                                        WICSPD
      IF(I.EQ.0) I=NS1                                                  WICSPD
      ALFA1=BET2SS(I)                                                   WICSPD
      ADEVSS(I)=ALFA1-BET2MS(I)                                         WICSPD
      CALL WICMAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,0.0,ALFA1,RMIX,        WICSPD
     $CPMIX,AREA(ISTAGE))                                               WICSPD
      CPMIX1=CPMIX                                                      WICSPD
      GAMMA1=GAMMA                                                      WICSPD
      VZ1=VZ                                                            WICSPD
      A1=C                                                              WICSPD
      M1=M                                                              WICSPD
      PS1=P(1)/(1.0+G2*M1**2)**G1                                       WICSPD
      TS1=TG(1)/(1.0+G2*M1**2)                                          WICSPD
      RHOGS1=PS1/RMIX/TS1                                               WICSPD
      FAIRIN=VZ1/UTIPG(ISTAGE)                                          WICSPD
      ALFA1R=ALFA1*PAI/180.0                                            WICSPD
      V1=VZ1/COS(ALFA1R)                                                WICSPD
      VS1=VZ1*WICTAN(ALFA1R)                                            WICSPD
      WS1=U(ISTAGE)-VS1                                                 WICSPD
      WV=WS1/VZ1                                                        WICSPD
      BETA1R=ATAN(WV)                                                   WICSPD
      BETA1=BETA1R*180.0/PAI                                            WICSPD
      BET1SR(ISTAGE)=BETA1                                              WICSPD
      AINCSR(ISTAGE)=BETA1-BET1MR(ISTAGE)                               WICSPD
      W1=VZ1/COS(BETA1R)                                                WICSPD
      M1REL=W1/A1                                                       WICSPD
      TREL1=(1.0+G2*M1REL**2)*TS1                                       WICSPD
      PREL1=(1.0+G2*M1REL**2)**G1*PS1                                   WICSPD
      IF(ISTAGE.GE.2) DS(ISTAGE-1)=1.0-V1/V2+ABS(VS2-VS1)/2.0/          WICSPD
     $SIGUMS(ISTAGE-1)/V2                                               WICSPD
```

```
      IF(ISTAGE.GE.2) DEQS(ISTAGE-1)=COS(ALFA1R)/COS(ALFA2R)*            WICSPD
     $(1.12+0.61*COS(ALFA2R)**2/SIGUMS(ISTAGE-1)*(WICTAN(ALFA2R)-        WICSPD
     $WICTAN(ALFA1R)))                                                   WICSPD
      IF(ISTAGE.GT.NS) GO TO 101                                         WICSPD
C ROTOR OUTLET                                                           WICSPD
      P(2)=PR12D(ISTAGE)*P(1)                                            WICSPD
      TR12=(PR12D(ISTAGE)**(1.0/G1)-1.0)/ETARD(ISTAGE)+1.0               WICSPD
      TG(2)=TR12*TG(1)                                                   WICSPD
      CALL WICPRP(1.0,0.0,0.0,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)           WICSPD
      GAMMA2=GAMMA                                                       WICSPD
      CPMIX2=CPMIX                                                       WICSPD
      GAMMAV=(GAMMA1+GAMMA2)/2.0                                         WICSPD
      CPMIXV=(CPMIX1+CPMIX2)/2.0                                         WICSPD
      G1AV=GAMMAV/(GAMMAV-1.0)                                           WICSPD
      G2AV=(GAMMAV-1.0)/2.0                                              WICSPD
      PR13I=(TG(2)/TG(1))**G1AV                                          WICSPD
      DELT=TG(2)-TG(1)                                                   WICSPD
      VS2=(U(ISTAGE)*VS1+DELT*CPMIXV*GC*AJ)/UU2(ISTAGE)                  WICSPD
      JJ=1                                                               WICSPD
      VZ2AS=VZ1                                                          WICSPD
  200 VS2VZ2=VS2/VZ2AS                                                   WICSPD
      ALFA2R=ATAN(VS2VZ2)                                                WICSPD
      ALFA2=ALFA2R*180.0/PAI                                             WICSPD
      BET1SS(ISTAGE)=ALFA2                                               WICSPD
      AINCSS(ISTAGE)=ALFA2-BET1MS(ISTAGE)                                WICSPD
      WS2=UU2(ISTAGE)-VS2                                                WICSPD
      WS2VZ2=WS2/VZ2AS                                                   WICSPD
      BETA2R=ATAN(WS2VZ2)                                                WICSPD
      BETA2=BETA2R*180.0/PAI                                             WICSPD
      BET2SR(ISTAGE)=BETA2                                               WICSPD
      ADEVSR(ISTAGE)=BETA2-BET2MR(ISTAGE)                                WICSPD
      V2=VZ2AS/COS(ALFA2R)                                               WICSPD
      W2=VZ2AS/COS(BETA2R)                                               WICSPD
      TS2=TG(2)-V2**2/(2.0*CPMIX2*GC*AJ)                                 WICSPD
      A2=SQRT(GAMMA2*RMIX*TS2*GC)                                        WICSPD
      M2=V2/A2                                                           WICSPD
      PS2=P(2)/(1.0+G2*M2**2)**G1                                        WICSPD
      RHOGS2=PS2/RMIX/TS2                                                WICSPD
      M2REL=W2/A2                                                        WICSPD
      TREL2=(1.0+G2*M2REL**2)*TS2                                        WICSPD
      PREL2=(1.0+M2REL**2)**G1*PS2                                       WICSPD
      VZ2CL=AMASS/(RHOGS2*AREAS(ISTAGE))                                 WICSPD
      EPS=1.0E-6                                                         WICSPD
      IF(JJ.EQ.2) GO TO 201                                              WICSPD
      IF(JJ.GT.2) GO TO 202                                              WICSPD
      X1=VZ2AS                                                           WICSPD
      Y1=VZ2CL                                                           WICSPD
      VZ2AS=VZ2CL                                                        WICSPD
      JJ=JJ+1                                                            WICSPD
      GO TO 200                                                          WICSPD
  201 X2=VZ2AS                                                           WICSPD
      Y2=VZ2CL                                                           WICSPD
      VZ2AS=WICNEW(X1,Y1,X2,Y2)                                          WICSPD
      JJ=JJ+1                                                            WICSPD
      GO TO 200                                                          WICSPD
  202 IF((ABS(VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 300                      WICSPD
      X1=X2                                                              WICSPD
      Y1=Y2                                                              WICSPD
      X2=VZ2AS                                                           WICSPD
      Y2=VZ2CL                                                           WICSPD
      VZ2AS=WICNEW(X1,Y1,X2,Y2)                                          WICSPD
      JJ=JJ+1                                                            WICSPD
      GO TO 200                                                          WICSPD
  300 VZ2=VZ2CL                                                          WICSPD
      FAIOUT=VZ2/UTIPG(ISTAGE)                                           WICSPD
      DR(ISTAGE)=1.0-W2/W1+ABS(WS1-WS2)/2.0/SIGUMR(ISTAGE)/W1            WICSPD
      DEQR(ISTAGE)=COS(BETA2R)/COS(BETA1R)*                              WICSPD
     $(1.12+0.61*COS(BETA1R)**2/SIGUMR(ISTAGE)*                          WICSPD
     $(WICTAN(BETA1R)-WICTAN(BETA2R)))                                   WICSPD
      PLOSSR=PR12D(ISTAGE)/(TG(2)/TG(1))**G1AV                           WICSPD
```

```
      PRRELI=(1.0+G2AV*U(ISTAGE)**2/(GAMMAV*RMIX*TREL1*GC)            WICSPD
     $*((UU2(ISTAGE)/U(ISTAGE))**2-1.0))**G1AV                        WICSPD
      IF(PRRELI.LT.PLOSSR) PRRELI=1.0                                 WICSPD
      OMEGR(ISTAGE)=(PRRELI-PLOSSR)/(1.0-PS1/PREL1)                   WICSPD
C STATOR OUTLET                                                       WICSPD
      PLOSSS=PR13D(ISTAGE)/PR12D(ISTAGE)                              WICSPD
      PR13=(TG(2)/TG(1))**G1AV*PLOSSR*PLOSSS                          WICSPD
      OMEGS(ISTAGE)=(1.0-PLOSSS)/(1.0-PS2/P(2))                       WICSPD
      ETASG=(PR13**(1.0/G1AV)-1.0)/(TR12-1.0)                         WICSPD
      P(3)=PR13*P(1)                                                  WICSPD
      TG(3)=TG(2)                                                     WICSPD
      TD(ISTAGE)=TG(1)                                                WICSPD
C PRINTOUT OF STAGE PERFORMANCE                                       WICSPD
      IF(IUNIT.EQ.2) THEN                                             WICSPD
      TG(1)=TG(1)*CFT                                                 WICSPD
      TG(2)=TG(2)*CFT                                                 WICSPD
      P(1)=P(1)*CFP                                                   WICSPD
      P(2)=P(2)*CFP                                                   WICSPD
      TS1=TS1*CFT                                                     WICSPD
      TS2=TS2*CFT                                                     WICSPD
      PS1=PS1*CFP                                                     WICSPD
      PS2=PS2*CFP                                                     WICSPD
      RHOGS1=RHOGS1*CFD                                               WICSPD
      RHOGS2=RHOGS2*CFD                                               WICSPD
      VZ1=VZ1*CFV                                                     WICSPD
      VZ2=VZ2*CFV                                                     WICSPD
      V1=V1*CFV                                                       WICSPD
      V2=V2*CFV                                                       WICSPD
      W1=W1*CFV                                                       WICSPD
      W2=W2*CFV                                                       WICSPD
      VS1=VS1*CFV                                                     WICSPD
      VS2=VS2*CFV                                                     WICSPD
      WS1=WS1*CFV                                                     WICSPD
      WS2=WS2*CFV                                                     WICSPD
      U(ISTAGE)=U(ISTAGE)*CFV                                         WICSPD
      UU2(ISTAGE)=UU2(ISTAGE)*CFV                                     WICSPD
      TREL1=TREL1*CFT                                                 WICSPD
      PREL1=PREL1*CFP                                                 WICSPD
      TREL2=TREL2*CFT                                                 WICSPD
      PREL2=PREL2*CFP                                                 WICSPD
      AREA(ISTAGE)=AREA(ISTAGE)*CFA                                   WICSPD
      AREAS(ISTAGE)=AREAS(ISTAGE)*CFA                                 WICSPD
      RADI1(ISTAGE)=RADI1(ISTAGE)*CFL                                 WICSPD
      RADI2(ISTAGE)=RADI2(ISTAGE)*CFL                                 WICSPD
      ENDIF                                                           WICSPD
      WRITE(6,1000)                                                   WICSPD
      WRITE(6,1100) ISTAGE                                            WICSPD
 1100 FORMAT(1H0,1X,≠***** STAGE=≠,I2,≠ *****≠)                       WICSPD
      WRITE(6,1101)                                                   WICSPD
 1101 FORMAT(1H0,16X,≠TOTAL≠,8X,≠TOTAL≠,7X,≠STATIC≠,7X,≠STATIC≠,7X,   WICSPD
     $≠STATIC≠,/,17X,≠TEMP≠,7X,≠PRESSURE≠,7X,≠TEMP≠,7X,≠PRESSURE≠,6X, WICSPD
     $≠DENSITY≠)                                                      WICSPD
      WRITE(6,1110) TG(1),P(1),TS1,PS1,RHOGS1                         WICSPD
 1110 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.3,3X))                     WICSPD
      WRITE(6,1120) TG(2),P(2),TS2,PS2,RHOGS2                         WICSPD
 1120 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.3,3X))                       WICSPD
      WRITE(6,1111)                                                   WICSPD
 1111 FORMAT(1H0,16X,≠AXIAL≠,6X,≠ABSOLUTE≠,5X,≠RELATIVE≠,5X,≠TAN COMP≠, WICSPD
     $5X,≠TAN COMP≠,/,15X,≠VELOCITY≠,5X,≠VELOCITY≠,5X,≠VELOCITY≠,4X,  WICSPD
     $≠OF ABS VEL≠,3X,≠OF REL VEL≠)                                   WICSPD
      WRITE(6,1130) VZ1,V1,W1,VS1,WS1                                 WICSPD
 1130 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.5,3X))                     WICSPD
      WRITE(6,1140) VZ2,V2,W2,VS2,WS2                                 WICSPD
 1140 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.5,3X))                       WICSPD
      WRITE(6,1141)                                                   WICSPD
 1141 FORMAT(1H0,15X,≠ROTOR≠,7X,≠ABS MACH≠,5X,≠REL MACH≠,5X,≠REL TOTAL≠, WICSPD
     $4X,≠REL TOTAL≠,/,16X,≠SPEED≠,8X,≠NUMBER≠,7X,≠NUMBER≠,7X,≠TEMP≠,8X, WICSPD
     $≠PRESSURE≠)                                                     WICSPD
      WRITE(6,1150) U(ISTAGE),M1,M1REL,TREL1,PREL1                    WICSPD
 1150 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.3,3X))                     WICSPD
```

```
      WRITE(6,1160) UU2(ISTAGE),M2,M2REL,TREL2,PREL2                    WICSPD
 1160 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.3,3X))                         WICSPD
      I=ISTAGE                                                          WICSPD
      IF(ISTAGE.EQ.1) I=8                                               WICSPD
      WRITE(6,1161)                                                     WICSPD
 1161 FORMAT(1H0,14X,≠ABS FLOW≠,5X,≠REL FLOW≠,4X,≠STREAMTUBE≠,18X,      WICSPD
     $≠FLOW≠,/,16X,≠ANGLE≠,8X,≠ANGLE≠,8X,≠AREA≠,9X,≠RADIUS≠,5X,        WICSPD
     $≠COEFFICIENT≠)                                                    WICSPD
      WRITE(6,1170) BET2SS(I-1),BET1SR(ISTAGE),AREA(ISTAGE),            WICSPD
     $RADI1(ISTAGE),FAIRIN                                              WICSPD
 1170 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.5,3X))                       WICSPD
      WRITE(6,1180) BET1SS(ISTAGE),BET2SR(ISTAGE),AREAS(ISTAGE),        WICSPD
     $RADI2(ISTAGE),FAIOUT                                              WICSPD
 1180 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.5,3X))                         WICSPD
      WRITE(6,1190) PR13,ETASG,PR12D(ISTAGE),ETARD(ISTAGE),TR12         WICSPD
 1190 FORMAT(1H0,1X,≠STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=≠,F10.5, WICSPD
     $/,2X,≠STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=≠,F10.5,/,2X,    WICSPD
     $≠ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=≠,F10.5,/,2X,         WICSPD
     $≠ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=≠,F10.5,/,2X,         WICSPD
     $≠ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=≠,F10.5)           WICSPD
      IF(IUNIT.EQ.2) THEN                                               WICSPD
      TG(1)=TG(1)/CFT                                                   WICSPD
      TG(2)=TG(2)/CFT                                                   WICSPD
      P(1)=P(1)/CFP                                                     WICSPD
      P(2)=P(2)/CFP                                                     WICSPD
      TS1=TS1/CFT                                                       WICSPD
      TS2=TS2/CFT                                                       WICSPD
      PS1=PS1/CFP                                                       WICSPD
      PS2=PS2/CFP                                                       WICSPD
      RHOGS1=RHOGS1/CFD                                                 WICSPD
      RHOGS2=RHOGS2/CFD                                                 WICSPD
      VZ1=VZ1/CFV                                                       WICSPD
      VZ2=VZ2/CFV                                                       WICSPD
      V1=V1/CFV                                                         WICSPD
      V2=V2/CFV                                                         WICSPD
      W1=W1/CFV                                                         WICSPD
      W2=W2/CFV                                                         WICSPD
      VS1=VS1/CFV                                                       WICSPD
      VS2=VS2/CFV                                                       WICSPD
      WS1=WS1/CFV                                                       WICSPD
      WS2=WS2/CFV                                                       WICSPD
      U(ISTAGE)=U(ISTAGE)/CFV                                           WICSPD
      UU2(ISTAGE)=UU2(ISTAGE)/CFV                                       WICSPD
      TREL1=TREL1/CFT                                                   WICSPD
      PREL1=PREL1/CFP                                                   WICSPD
      TREL2=TREL2/CFT                                                   WICSPD
      PREL2=PREL2/CFP                                                   WICSPD
      AREA(ISTAGE)=AREA(ISTAGE)/CFA                                     WICSPD
      AREAS(ISTAGE)=AREAS(ISTAGE)/CFA                                   WICSPD
      RADI2(ISTAGE)=RADI2(ISTAGE)/CFL                                   WICSPD
      ENDIF                                                             WICSPD
C REPEAT                                                                WICSPD
      TG(1)=TG(3)                                                       WICSPD
      P(1)=P(3)                                                         WICSPD
      IF(ISTAGE.EQ.NS) ADEVSS(NS)=BET2SS(NS)-BET2MS(NS)                 WICSPD
      ISTAGE=ISTAGE+1                                                   WICSPD
      IF(ISTAGE.EQ.NS1) GO TO 101                                       WICSPD
      GO TO 100                                                         WICSPD
C OVERALL PERFORMANCE AT DESIGN POINT                                   WICSPD
  101 OVALPR=P(3)/POIN                                                  WICSPD
      OVALTR=TG(3)/TOIN                                                 WICSPD
      GAMMAV=(GAMAIN+GAMMA)/2.0                                         WICSPD
      G1AV=GAMMAV/(GAMMAV-1.0)                                          WICSPD
      OVALEF=(OVALPR**(1.0/G1AV)-1.0)/(OVALTR-1.0)                      WICSPD
      OVALDT=TG(3)-TOIN                                                 WICSPD
C PRINTOUT OF OVERALL PERFORMANCE AT DESIGN POINT                       WICSPD
      IF(IUNIT.EQ.2) THEN                                               WICSPD
      TOIN=TOIN*CFT                                                     WICSPD
      POIN=POIN*CFP                                                     WICSPD
      CMASS=CMASS*CFM                                                   WICSPD
```

```
      OVALDT=OVALDT*CFT
      DO 422 I=1,NS
      TD(I)=TD(I)*CFT
  422 CONTINUE
      ENDIF
      WRITE(6,1000)
      WRITE(6,421)
  421 FORMAT(1H0,≠*********** OVERALL PERFORMANCE AT DESIGN POINT ****
     $*******≠)
      WRITE(6,425) TOIN
  425 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL TEMPERATURE=≠,F8.2)
      WRITE(6,426) POIN
  426 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      WRITE(6,427) CMASS
  427 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE=≠,F6.3)
      WRITE(6,429) OVALPR
  429 FORMAT(1H0,1X,≠OVERALL TOTAL PRESSURE RATIO=≠,F6.4)
      WRITE(6,430) OVALTR
  430 FORMAT(1H0,1X,≠OVERALL TOTAL TEMPERATURE RATIO=≠,F6.4)
      WRITE(6,431) OVALEF
  431 FORMAT(1H0,1X,≠OVERALL ADIABATIC EFFICIENCY=≠,F6.4)
      WRITE(6,432) OVALDT
  432 FORMAT(1H0,1X,≠OVERALL TEMPERATURE RISE=≠,F8.3)
      WRITE(6,1621)
 1621 FORMAT(1H0,14X,≠1≠,5X,≠2≠,5X,≠3≠,5X,≠4≠,5X,≠5≠,5X,≠6≠,4X,≠IGV≠)
      WRITE(6,1710) (BET1SR(I),I=1,NS)
 1710 FORMAT(1H ,1X,≠BET1SR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1720) (BET2SR(I),I=1,NS)
 1720 FORMAT(1H ,1X,≠BET2SR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1730) (AINCSR(I),I=1,NS)
 1730 FORMAT(1H ,1X,≠AINCSR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1740) (ADEVSR(I),I=1,NS)
 1740 FORMAT(1H ,1X,≠ADEVSR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1760) (BET1SS(I),I=1,NS)
 1760 FORMAT(1H ,1X,≠BET1SS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1770) (BET2SS(I),I=1,NS1)
 1770 FORMAT(1H ,1X,≠BET2SS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1780) (AINCSS(I),I=1,NS)
 1780 FORMAT(1H ,1X,≠AINCSS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1790) (ADEVSS(I),I=1,NS)
 1790 FORMAT(1H ,1X,≠ADEVSS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1791) (TD(I),I=1,NS)
 1791 FORMAT(1H ,1X,≠TD(I)≠,6X,6(F5.1,1X))
      WRITE(6,1793) (OMEGS(I),I=1,NS)
 1793 FORMAT(1H ,1X,≠OMEGS(I)≠,3X,6(F5.3,1X))
      WRITE(6,1794) (OMEGR(I),I=1,NS)
 1794 FORMAT(1H ,1X,≠OMEGR(I)≠,3X,6(F5.3,1X))
      IF(IUNIT.EQ.2) THEN
      TOIN=TOIN/CFT
      POIN=POIN/CFP
      CMASS=CMASS/CFM
      OVALDT=OVALDT/CFT
      DO 423 I=1,NS
      TD(I)=TD(I)*CFT
  423 CONTINUE
      ENDIF
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C *** STGSTK - A COMPUTER CODE FOR PREDICTING MULTISTAGE AXIAL FLOW   C
C     COMPRESSOR PERFORMANCE USING A MEANLINE STAGE STACKING METHOD.  C
C     DOCUMENTATION  NASA TP-XXXX, XXX, 1980, BY R. J. STEINKE        C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE NASA
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
```

```
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                                NASA
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                         NASA
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                         NASA
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)        NASA
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)        NASA
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI       NASA
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT       NASA
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                           NASA
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                       NASA
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)             NASA
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                   NASA
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)        NASA
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),     NASA
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),       NASA
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9 NASA
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),        NASA
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), NASA
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12) NASA
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)  NASA
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(   NASA
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12 NASA
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)        NASA
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR NASA
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)   NASA
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)                        NASA
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)                              NASA
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)           NASA
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)              NASA
     *,PSI4(12,2,8),PSI5(12,2,8)                                         NASA
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                      NASA
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                       NASA
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)           NASA
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA NASA
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                        NASA
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP     NASA
     X,XAR,XMET,XSTM                                                     NASA
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                       NASA
C *** CALCULATE FIXED PARAMETERS                                          NASA
      PO = PO*144.0                                                      NASA
      DO 20  I=1,NSTA                                                    NASA
      AREA2(I)= (RT2(I)+RH2(I))*(RT2(I)-RH2(I))*PI/144.0                 NASA
      AREA3(I)= (RT3(I)+RH3(I))*(RT3(I)-RH3(I))*PI/144.0                 NASA
      IF(IRAD.EQ.1) RM2(I)=RT2(I)                                        NASA
      IF(IRAD.EQ.1) RM3(I)=RT3(I)                                        NASA
      IF(IRAD.EQ.2) RM2(I)=RM(I)                                         NASA
      IF(IRAD.EQ.2) RM3(I)=SM(I)                                         NASA
      IF(IRAD.EQ.3) RM2(I)=RH2(I)                                        NASA
      IF(IRAD.EQ.3) RM3(I)=RH3(I)                                        NASA
      AREA2(I)=SAREA(I)                                                  NASA
      AREA3(I)=SAREAS(I)                                                 NASA
      UM2(I)= RM2(I)*DESRPM*RPMRAD                                       NASA
      UM3(I)= RM3(I)*DESRPM*RPMRAD                                       NASA
      BET2M(I,1) = BET2M(I,1)/RAD                                        NASA
      RK2M(I) = RK2M(I) + CB2MR(I)                                       NASA
      SK2M(I) = SK2M(I) + CB2M(I)                                        NASA
      CB2M(I)= CB2M(I)/RAD                                               NASA
      CB2MR(I)= CB2MR(I)/RAD                                             NASA
      CB3MR(I)= CB3MR(I)/RAD                                             NASA
   20 CONTINUE                                                           NASA
      CALL CSPREF                                                        NASA
      IF(ETADES(1,1,1) .EQ. 0.0)  CALL CSETA                             NASA
      CALL CSPSI(0.00,1)                                                 NASA
      DO 100 I=1,NSTA                                                    NASA
      DO 100 K=1,NPTS                                                    NASA
      PSID1(I,1,K)=PSIDES(I,1,K)                                         NASA
  100 CONTINUE                                                           NASA
      CALL CSPSI(0.025,1)                                                NASA
      DO 101 I=1,NSTA                                                    NASA
      DO 101 K=1,NPTS                                                    NASA
      PSID2(I,1,K)=PSIDES(I,1,K)                                         NASA
```

```
  101 CONTINUE
      CALL CSPSI(0.075,1)
      DO 102 I=1,NSTA
      DO 102 K=1,NPTS
      PSID3(I,1,K)=PSIDES(I,1,K)
  102 CONTINUE
      CALL CSPSI(0.125,1)
      DO 103 I=1,NSTA
      DO 103 K=1,NPTS
      PSID4(I,1,K)=PSIDES(I,1,K)
  103 CONTINUE
      CALL CSPSI(0.150,1)
      DO 104 I=1,NSTA
      DO 104 K=1,NPTS
      PSID5(I,1,K)=PSIDES(I,1,K)
  104 CONTINUE
      CALL CSPSI(0.00,2)
      DO 200 I=1,NSTA
      DO 200 K=1,NPTS
      PSID1L(I,1,K)=PSIDES(I,1,K)
  200 CONTINUE
      CALL CSPSI(0.025,2)
      DO 201 I=1,NSTA
      DO 201 K=1,NPTS
      PSID2L(I,1,K)=PSIDES(I,1,K)
  201 CONTINUE
      CALL CSPSI(0.075,2)
      DO 202 I=1,NSTA
      DO 202 K=1,NPTS
      PSID3L(I,1,K)=PSIDES(I,1,K)
  202 CONTINUE
      CALL CSPSI(0.125,2)
      DO 203 I=1,NSTA
      DO 203 K=1,NPTS
      PSID4L(I,1,K)=PSIDES(I,1,K)
  203 CONTINUE
      CALL CSPSI(0.150,2)
      DO 204 I=1,NSTA
      DO 204 K=1,NPTS
      PSID5L(I,1,K)=PSIDES(I,1,K)
  204 CONTINUE
      DO 800 I=1,12
      DO 800 J=1,NSPE
      DPSIS(I,J)=0.0
  800 CONTINUE
      IF (SPDPSI.EQ.1.0) CALL CSPSD
      CALL CSPAN
      DO 51 I=1,NSTA
      BET2M(I,1) = BET2M(I,1) * RAD
   51 BET3MR(I,1) = BET3MR(I,1) * RAD
C *** WRITE INTERMEDIATE OUTPUT
      WRITE (6,2120)
      IF(UNITS.EQ.1.0) THEN
      DO 300 I=1,NSTA
      FLOCAL(I,1)=FLOCAL(I,1)*0.453592
  300 CONTINUE
      ENDIF
      WRITE (6,2051) (NSTAGE(I),PHIREF(I),PSIREF(I),ETAREF(I),CPREF(I),
     XGMREF(I),FLOCAL(I,1),
     X                 BET2M(I,1),BET3MR(I,1),RINCM(I),RDFM(I),SINCM(I),
     XI=1,NSTA)
      IF(UNITS.EQ.1.0) THEN
      DO 310 I=1,NSTA
      FLOCAL(I,1)=FLOCAL(I,1)/0.453592
  310 CONTINUE
      ENDIF
 2051 FORMAT (110H     STAGE     PHIREF     PSIREF     ETAREF      CPREF
     X GMREF     FLOCAL      BET2M      BET3MR      RINCM       RDFM,10H     S
     XINCM//(5X,I5,5F10.4,4F10.2,F10.4,F10.2))
      WRITE(6,3474)
```

```
 3474 FORMAT(1H-≠ STAGE     VZ2M        VZ3M≠)                              NASA
      DO 177 I=1,NSTA                                                       NASA
      WRITE(6,3473) I,VZ2M(I,1),VZ3M(I,1)                                   NASA
 3473 FORMAT(4X,I2,F14.2,F11.2)                                             NASA
  177 CONTINUE                                                              NASA
      DO 52 I=1,NSTA                                                        NASA
      BET2M(I,1) = BET2M(I,1) / RAD                                         NASA
   52 BET3MR(I,1) = BET3MR(I,1) / RAD                                       NASA
      WRITE (6,2120)                                                        NASA
      WRITE (6,2052) (NSTAGE(I),I=1,12), (PCTSPD(J), (DPSIS(I,J), I=1,12    NASA
     1),J=1,NSPE)                                                           NASA
 2052 FORMAT (20X,27H DPSIS(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER/    NASA
     18H PCT SPD,12(I5,3X)//(13F8.4))                                       NASA
      DO 60  I=1,NSTA                                                       NASA
      DO 60  J=1,NSPE                                                       NASA
      DO 60  K=1,NPTS                                                       NASA
      PHI(I,J,K)=PHIDES(I,J,K)                                              NASA
      IF (SPDPHI.EQ.1.0) PHI(I,J,K) = PHI(I,J,K)*(1.0 + ((PHI(I,J,K)/PHI    NASA
     XREF(I))**(1.0/SPEEDF) - 1.0)*1.0*ABS(1.0 - SPEEDF))                   NASA
C *** OPTION TO ALTER FLOW COEFICIENT FOR OFF DESIGN SPEEDS                   NASA
      PSI1(I,J,K)=PSID1(I,1,K)                                              NASA
      PSI2(I,J,K)=PSID2(I,1,K)                                              NASA
      PSI3(I,J,K)=PSID3(I,1,K)                                              NASA
      PSI4(I,J,K)=PSID4(I,1,K)                                              NASA
      PSI5(I,J,K)=PSID5(I,1,K)                                              NASA
      PSI(I,J,K)=PSI1(I,1,K)                                                NASA
      PSI1L(I,J,K)=PSID1L(I,1,K)                                            NASA
      PSI2L(I,J,K)=PSID2L(I,1,K)                                            NASA
      PSI3L(I,J,K)=PSID3L(I,1,K)                                            NASA
      PSI4L(I,J,K)=PSID4L(I,1,K)                                            NASA
      PSI5L(I,J,K)=PSID5L(I,1,K)                                            NASA
      ETA(I,J,K) = ETADES(I,1,K)*ETARAT(J) + DETA(I)                        NASA
   60 CONTINUE                                                              NASA
      DO 70  I=1,NSTA                                                       NASA
      WRITE (6,2120)                                                        NASA
      WRITE(6,2060) NSTAGE(I),((PHI(I,J,K),PSI(I,J,K),                      NASA
     1ETA(I,J,K),J=1,1),K=1,NPTS)                                           NASA
      IF(NSPE.LT.4)  GO TO 70                                               NASA
      WRITE (6,2120)                                                        NASA
      WRITE(6,2060) NSTAGE(I),((PHI(I,J,K),PSI(I,J,K),                      NASA
     1ETA(I,J,K),J=4,6),K=1,NPTS)                                           NASA
      IF(NSPE.LT.7) GO TO 70                                                NASA
      WRITE (6,2120)                                                        NASA
      WRITE(6,2060) NSTAGE(I),((PHI(I,J,K),PSI(I,J,K),                      NASA
     1ETA(I,J,K),J=7,9),K=1,NPTS)                                           NASA
   70 CONTINUE                                                              NASA
 2060 FORMAT (20X,39H COMPUTED CHARACTERISTICS FOR STAGE NO.,I3//           NASA
     13(30H   PHI        PSI        ETA     )/(9F1                          NASA
     20.4))                                                                 NASA
 2120 FORMAT (1H0////)                                                      NASA
      RETURN                                                                NASA
      END                                                                   NASA
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ CSINPT
      SUBROUTINE CSINPT                                                     CSINPT
C *** SUBROUTINE CSINPT READS AND WRITES THE INPUT DATA                       CSINPT
C *** ALL INPUT DATA MUST BE ENGLISH UNIT                                     CSINPT
C *** VALUE OF INPUT DATA ≠SPEEDN≠ MUST ALWAYS BE 1.0                         CSINPT
C *** VALUE OF INPUT DATA ≠UNITS≠ MUST ALWAYS BE 0.0                          CSINPT
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),        CSINPT
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),          CSINPT
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9    CSINPT
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),           CSINPT
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),    CSINPT
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)    CSINPT
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)     CSINPT
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(      CSINPT
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12    CSINPT
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)           CSINPT
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR    CSINPT
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)      CSINPT
```

```
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)                        CSINPT
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)                              CSINPT
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)           CSINPT
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)              CSINPT
     *,PSI4(12,2,8),PSI5(12,2,8)                                         CSINPT
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                      CSINPT
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                       CSINPT
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)           CSINPT
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA CSINPT
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                        CSINPT
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP     CSINPT
     X,XAR,XMET,XSTM                                                     CSINPT
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                       CSINPT
      DIMENSION PHIINP(10)                                               CSINPT
      READ(5,1000) (TITLE(I),I=1,12)                                     CSINPT
      WRITE(6,2000) (TITLE(I),I=1,12)                                    CSINPT
 1000 FORMAT (12A6)                                                      CSINPT
 2000 FORMAT (1H1////20X,30H ** STAGE STACKING PROGRAM ** ////20X,       CSINPT
     112A6////)                                                          CSINPT
      READ (5,4444) STAGEN, SPEEDN, CHAPTS ,PO,TO,DESRPM,DESFLO          CSINPT
 4444 FORMAT(7F10.0)                                                     CSINPT
      WRITE(6,2010) STAGEN, SPEEDN, CHAPTS ,PO,TO,DESRPM,DESFLO          CSINPT
      READ(5,1008) WTMOLA,WTMOLM,WTMOLS,XAR,XMET,XSTM                    CSINPT
 1008 FORMAT(6F10.0)                                                     CSINPT
      RGAIR=RU/WTMOLA                                                    CSINPT
      RGMET=RU/WTMOLM                                                    CSINPT
      RGSTM=RU/WTMOLS                                                    CSINPT
      RG=RGAIR*XAR+RGMET*XMET+RGSTM*XSTM                                 CSINPT
      WTMOLE=RU/RG                                                       CSINPT
      WRITE(6,1006)WTMOLA,WTMOLM,WTMOLS,WTMOLE                           CSINPT
 1006 FORMAT(1H-,5X,≠MW AIR=≠,F7.4,3X,≠MW METHANE=≠,F7.4,3X,≠MW STEAM=≠, CSINPT
     *F7.4,3X,≠MW MIXTURE=≠,F7.4)                                        CSINPT
      WRITE(6,1004) XAR,XMET,XSTM                                        CSINPT
 1004 FORMAT(1H-,5X,≠MASS FRACTION AIR=≠,F6.4,5X,≠MASS FRACTION METHANE= CSINPT
     *≠,F6.4,5X,≠MASS FRACTION STEAM=≠,F6.4)                             CSINPT
      DCP = RG/AJ                                                        CSINPT
      GJ = G*AJ                                                          CSINPT
      G2J = GJ*2.0                                                       CSINPT
      RPMRAD = PI/360.0                                                  CSINPT
 1010 FORMAT (8F10.0)                                                    CSINPT
 2010 FORMAT (72H    STAGES    SPEEDS    POINTS     PO IN     TO IN   DES CSINPT
     * RPM     DES FLOW//(7F10.3)////)                                   CSINPT
      READ (5,1010) SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP, UNITS        CSINPT
      WRITE (6,2011) SPDPSI, SPDPHI,DRDEVG, DRDEVN, DRDEVP, UNITS        CSINPT
 2011 FORMAT (60H    SPDPSI    SPDPHI    DRDEVG    DRDEVN    DRDEVP      CSINPT
     XUNITS//(6F10.1)////)                                               CSINPT
      READ (5,1020) (CPCO(I),I=1,6)                                      CSINPT
      WRITE(6,2020) (CPCO(I),I=1,6)                                      CSINPT
 1020 FORMAT (3E20.8)                                                    CSINPT
      READ(5,1020) (CPCM(I),I=1,6)                                       CSINPT
      WRITE(6,2021) (CPCM(I),I=1,6)                                      CSINPT
      READ(5,1020) (CPCS(I),I=1,6)                                       CSINPT
      WRITE(6,2022) (CPCS(I),I=1,6)                                      CSINPT
 2020 FORMAT (072H      CPCO(1)      CPCO(2)      CPCO(3)      CPCO(4)      C CSINPT
     1PCO(5)      CPCO(6)//(6E12.5)////)                                 CSINPT
 2021 FORMAT (072H      CPCM(1)      CPCM(2)      CPCM(3)      CPCM(4)      C CSINPT
     1PCM(5)      CPCM(6)//(6E12.5)////)                                 CSINPT
 2022 FORMAT (072H      CPCS(1)      CPCS(2)      CPCS(3)      CPCS(4)      C CSINPT
     1PCS(5)      CPCS(6)//(6E12.5)////)                                 CSINPT
      NSTA = STAGEN                                                      CSINPT
      NSPE= SPEEDN                                                       CSINPT
      NPTS = CHAPTS                                                      CSINPT
      READ (5,1010) (RT2(I),I=1,NSTA)                                    CSINPT
      READ (5,1010) (RH2(I),I=1,NSTA)                                    CSINPT
      READ (5,1010) (RT3(I),I=1,NSTA)                                    CSINPT
      READ (5,1010) (RH3(I),I=1,NSTA)                                    CSINPT
      READ (5,1010) (BET2M(I,1),I=1,NSTA)                                CSINPT
      READ (5,1010) (CB2M(I),   I=1,NSTA)                                CSINPT
      READ (5,1010) (CB2MR(I),  I=1,NSTA)                                CSINPT
      READ (5,1010) (CB3MR(I),  I=1,NSTA)                                CSINPT
```

```
      READ (5,1010) (RK2M (I), I=1,NSTA)                                  CSINPT
      READ(5,1010) (RK3M(I),I=1,NSTA)                                     CSINPT
      READ (5,1010) (RSOLM(I), I=1,NSTA)                                  CSINPT
      READ (5,1010) (SK2M(I),I=1,NSTA)                                    CSINPT
      READ (5,1010) (PR(I),I=1,NSTA)                                      CSINPT
      READ(5,1010) (ETAINP(I),I=1,NSTA)                                   CSINPT
      READ(5,1010) (PHIINP(I),I=1,NSTA)                                   CSINPT
      WRITE(6,2030) (NSTAGE(I),RT2(I),RH2(I),RT3(I),RH3(I),BET2M(I,1),    CSINPT
     XCB2M(I),CB2MR(I),CB3MR(I),RK2M(I),RSOLM(I),SK2M(I), I=1,NSTA)       CSINPT
 2030 FORMAT (110H     STAGE        RT2         RH2         RT3        RH3 CSINPT
     X BET2M        CB2M       CB2MR      CB3MR        RK2M      RSOLM,10H CSINPT
     XSK2M//(5X,I5,4F10.4,5F10.2,F10.4,F10.2))                            CSINPT
      WRITE (6,2120)                                                      CSINPT
      WRITE (6,2031) (NSTAGE(I), PR(I), ETAINP(I), I=1,NSTA)              CSINPT
 2031 FORMAT (30H     STAGE         PR     ETAINP//(5X,I5,2F10.4))        CSINPT
      READ(5,1010) (PCTSPD(J),J=1,NSPE)                                   CSINPT
      PCTSPD(1)=1.0                                                       CSINPT
 2120 FORMAT (1H0////)                                                    CSINPT
      READ (5,1010) (ETARAT(J),J=1,NSPE)                                  CSINPT
      WRITE (6,2120)                                                      CSINPT
      WRITE (6,2121) (PCTSPD(J),ETARAT(J), J=1,NSPE)                      CSINPT
 2121 FORMAT (20H    PCTSPD    ETARAT//(2F10.4))                          CSINPT
      DO 21 I=1,NSTA                                                      CSINPT
      READ (5,1010) (BLEED(I,J),J=1,NSPE)                                 CSINPT
   21 CONTINUE                                                            CSINPT
      WRITE (6,2120)                                                      CSINPT
      WRITE (6,2041) (NSTAGE(I),I=1,12), (PCTSPD(J), (BLEED(I,J), I=1,12  CSINPT
     1),J=1,NSPE)                                                         CSINPT
 2041 FORMAT (20X,27H BLEED(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER/  CSINPT
     18H PCT SPD,12(I5,3X)//(13F8.3))                                     CSINPT
      DO 30  I=1,NSTA                                                     CSINPT
      READ (5,1011) (PHIDES(I,1,K),K=1,NPTS)                              CSINPT
      READ (5,1012) (PSIDES(I,1,K),K=1,NPTS)                              CSINPT
      READ (5,1013) (ETADES(I,1,K),K=1,NPTS)                              CSINPT
   30 CONTINUE                                                            CSINPT
      DO 300 I=1,NSTA                                                     CSINPT
      DO 301 K=1,NPTS                                                     CSINPT
      PHIPHI=PHIDES(I,1,K)/PHIINP(I)                                      CSINPT
      ISPD=IFIX(SPEEDF*100.0)                                             CSINPT
      DELPHI=DPHI(I,ISPD)                                                 CSINPT
      PHIPHI=PHIPHI+DELPHI                                                CSINPT
      PHIDES(I,1,K)=PHIPHI*PHIINP(I)                                      CSINPT
  301 CONTINUE                                                            CSINPT
  300 CONTINUE                                                            CSINPT
 1011 FORMAT(8F10.0)                                                      CSINPT
 1012 FORMAT(8F10.0)                                                      CSINPT
 1013 FORMAT(8F10.0)                                                      CSINPT
      DO 50  I=1,NSTA                                                     CSINPT
      WRITE (6,2120)                                                      CSINPT
      WRITE(6,2050) NSTAGE(I),((PHIDES(I,J,K),PSIDES(I                    CSINPT
     1,J,K),ETADES(I,J,K),J=1,1),K=1,NPTS)                                CSINPT
      IF(NSPE.LT.4) GO TO 50                                              CSINPT
      WRITE (6,2120)                                                      CSINPT
      WRITE(6,2050) NSTAGE(I),((PHIDES(I,J,K),PSIDES(I                    CSINPT
     1,J,K),ETADES(I,J,K),J=4,6),K=1,NPTS)                                CSINPT
      IF(NSPE.LT.7) GO TO 50                                              CSINPT
      WRITE (6,2120)                                                      CSINPT
      WRITE(6,2050) NSTAGE(I),((PHIDES(I,J,K),PSIDES(I                    CSINPT
     1,J,K),ETADES(I,J,K),J=7,9),K=1,NPTS)                                CSINPT
   50 CONTINUE                                                            CSINPT
 2050 FORMAT (20X,41H INPUT DESIGN CHARACTERISTICS FOR STAGE--,I3//       CSINPT
     13(30H    PHIDES    PSIDES    ETADES)/(9F1                           CSINPT
     20.4))                                                               CSINPT
C *** CHANGE METRIC INPUT INTO ENGLISH UNITS                               CSINPT
      IF (UNITS.NE.1.0) GO TO 53                                          CSINPT
      PO = PO/0.689476                                                    CSINPT
      TO = TO*9.0/5.0                                                     CSINPT
      DESFLO = DESFLO/0.453592                                            CSINPT
      DO 51 I=1,NSTA                                                      CSINPT
      RT2(I) = RT2(I)/2.54                                                CSINPT
```

```
      RH2(I) = RH2(I)/2.54
      RT3(I) = RT3(I)/2.54
      RH3(I) = RH3(I)/2.54
      DO 52 J = 1,NSPE
   52 BLEED(I,J) = BLEED(I,J)/0.453592
   51 CONTINUE
   53 RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      SUBROUTINE CSPREF
C *** SUBROUTINE CSPREF CALCULATES PARAMETERS AT DESIGN SPEED AND FLOW
C     CONDITIONS
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)
     *,PSI4(12,2,8),PSI5(12,2,8)
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
     X,XAR,XMET,XSTM
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE
      J= 1
      I= 1
      TT(I)= TO
      PT(I)= PO
   20 RHOT=PT(I)/(TT(I)*RG)
      TS= TT(I)
      RHOS= RHOT
      UT2(I)= RT2(I)*DESRPM*RPMRAD
      UT3(I)= RT3(I)*DESRPM*RPMRAD
C *** CALCULATIONS AT ROTOR INLET
   30 VZ2M(I,J) = DESFLO/(RHOS*AREA2(I))
      V= VZ2M(I,J)/COS(BET2M(I,J))
      CP=CPFM(TS)
      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))**GF1
      TS= TT(I)*(RHOS/RHOT)**GM1
      WCAL= RHOS*AREA2(I)*VZ2M(I,J)
      IF((ABS(WCAL - DESFLO)/WCAL) .GT. 0.005)  GO TO 30
      CPREF(I) = CP
      GMREF(I)=GAMMA
      GF1REF(I) = GF1
      PHIREF(I)= VZ2M(I,J)/UT2(I)
      DO 40  K=2,NPTS
      IF(PHIREF(I)-PHIDES(I,J,K))  50,60,40
   40 CONTINUE
      K= NPTS
   50 PSIREF(I)= (PSIDES(I,J,K)-PSIDES(I,J,K-1))*(PHIREF(I)-PHIDES(I,J,
     1K-1))/    (PHIDES(I,J,K)-PHIDES(I,J,K-1)) + PSIDES(I,J,K-1)
      ETAREF(I)= (ETADES(I,J,K)-ETADES(I,J,K-1))*(PHIREF(I)-PHIDES(I,J,
     1K-1))/    (PHIDES(I,J,K)-PHIDES(I,J,K-1)) + ETADES(I,J,K-1)
      GO TO 70
   60 PSIREF(I)= PSIDES(I,J,K)
      ETAREF(I)= ETADES(I,J,K)
   70 CONTINUE
```

```
      IF (PSIREF(I).EQ.0.0) GO TO 71
      PR(I)= (1.0 + PSIREF(I)*UT3(I)*UT3(I)/(GJ*CP*TT(I)))**GF2
   71 CONTINUE
      IF(ETAREF(I).EQ.0.0)  ETAREF(I)= ETAINP(I)
      TR(I)= 1.0 + (PR(I)**GF3-1.0)/ETAREF(I)
      TT(I+1)= TT(I)*TR(I)
      IF (PSIREF(I).EQ.0.0) PSIREF(I) = GJ*CP*(TT(I+1)-TT(I))*ETAREF(I)
     X/UT3(I)**2
      PT(I+1)= PT(I)*PR(I)
      TRO(I)= TT(I+1)/TO
      PRO(I)= PT(I+1)/PO
      I= I+1
      IF(I .LE. NSTA)  GO TO 20
      DO 80  I=1,NSTA
      VT2M= VZ2M(I,J)*TAN(BET2M(I,J))
      VT2MR= UM2(I) - VT2M
      BAT2MR(I,J)= ATAN2(VT2MR,VZ2M(I,J))
      TS= TT(I+1)
      RHOT= PT(I+1)/(TT(I+1)*RG)
      RHOS= RHOT
C *** CALCULATIONS AT ROTOR OUTLET
   81 VZ3M(I,J)= DESFLO/(RHOS*AREA3(I))
      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UM2(I)*VT2M)/UM3(I)
      V= SQRT(VZ3M(I,J)**2 + VT3M**2)
      CP=CPFM(TS)
      RHOS = RHOT*(1.0-V*V/(G2J*CP*TT(I+1)))**GF1
      TS = TT(I+1)*(RHOS/RHOT)**GM1
      WCAL= RHOS*AREA3(I)*VZ3M(I,J)
      IF((ABS(WCAL-DESFLO)/WCAL) .GT. 0.005)  GO TO 81
      BET3M(I,J) = ATAN2(VT3M,VZ3M(I,J))
      SINCM(I) = BET3M(I,J)*RAD - SK2M(I)
      VT3MR= UM3(I) - VT3M
      BET3MR(I,J)= ATAN2(VT3MR,VZ3M(I,J))
      RINCM(I)= BAT2MR(I,J)*RAD - RK2M(I)
      V2MR= VZ2M(I,J)/COS(BAT2MR(I,J))
      V3MR= VZ3M(I,J)/COS(BET3MR(I,J))
      V3DV2R(I) = V3MR/V2MR
      IF(I.EQ.NSTA) GO TO 82
      V2M=VZ2M(I+1,J)/COS(BET2M(I+1,J))
      V3M=V
      V2V3(I)=V2M/V3M
   82 CONTINUE
      RDFM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +
     XRM2(I))/RSOLM(I)/V2MR
      DB2M(I,J) = BET2M(I,J)
      DB2MR(I,J) = BAT2MR(I,J)
      DB3M(I,J) = BET3M(I,J)
      DB3MR(I,J) = BET3MR(I,J)
      B2MB3R(I,J)  = BAT2MR(I,J) - BET3MR(I,J)
   80 CONTINUE
      RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      FUNCTION CPFM(TS)
C *** SUBROUTINE CPFM(TS) CALCULATES SPECIFIC HEAT FROM STATIC
C     TEMPERATURE USING FIFTH DEGREE POLYNOMIAL
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)
```

```
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)          CPFM
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)             CPFM
     *,PSI4(12,2,8),PSI5(12,2,8)                                        CPFM
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                     CPFM
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                      CPFM
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)          CPFM
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA CPFM
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                       CPFM
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP    CPFM
     X,XAR,XMET,XSTM                                                    CPFM
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                      CPFM
      TS=TS/1.8                                                         CPFM
      CPA=(CPCO(1)+(CPCO(2)*TS)+(CPCO(3)*TS*TS)+(CPCO(4)*TS*TS*TS)+(CPCO CPFM
     *(5)*TS*TS*TS*TS))*287.056                                         CPFM
      CPS=(CPCS(1)+(CPCS(2)*TS)+(CPCS(3)*TS*TS)+(CPCS(4)*TS*TS*TS)+(CPCS CPFM
     *(5)*TS*TS*TS*TS))*461.495                                         CPFM
      CPM=(CPCM(1)+(CPCM(2)*TS)+(CPCM(3)*TS*TS)+(CPCM(4)*TS*TS*TS)+(CPCM CPFM
     *(5)*TS*TS*TS*TS))*518.251                                         CPFM
      CPFM=((CPA*XAR)+(CPS*XSTM)+(CPM*XMET))/4177.8                     CPFM
      TS=TS*1.8                                                         CPFM
      GAMMA=CPFM/(CPFM-DCP)                                             CPFM
      GM1 =  GAMMA - 1.0                                                CPFM
      GF1 =  1.0/GM1                                                    CPFM
      GF2 =  GAMMA/GM1                                                  CPFM
      GF3 =  1.0/GF2                                                    CPFM
      RETURN                                                            CPFM
      END                                                               CPFM
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ CSETA
      SUBROUTINE CSETA                                                  CSETA
C *** SUBROUTINE CSETA GENERATES ADIABATIC EFFICIENCY VERSUS FLOW       CSETA
C     COEFICIENT                                                        CSETA
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),    CSETA
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      CSETA
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9 CSETA
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),       CSETA
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), CSETA
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12) CSETA
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) CSETA
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  CSETA
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12 CSETA
     X,9), PHIFIX(12), DPHIF(12),CFREF(12), GF1REF(12),ETAINP(12)       CSETA
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR CSETA
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)  CSETA
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)                       CSETA
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)                             CSETA
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)          CSETA
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)             CSETA
     *,PSI4(12,2,8),PSI5(12,2,8)                                        CSETA
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                     CSETA
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                      CSETA
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)          CSETA
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA CSETA
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                       CSETA
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP    CSETA
     X,XAR,XMET,XSTM                                                    CSETA
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                      CSETA
      J = 1                                                             CSETA
C *** TWO PARABOLAS ARE USED FROM STALL AND CHOKE TO DESIGN CONDITIONS  CSETA
      DO 10  I=1,NSTA                                                   CSETA
      RAM=0.76                                                          CSETA
      PSMPRS= (PHIDES(I,J,1) - PHIREF(I))**2                            CSETA
      PCMPRS = (PHIDES(I,J,NPTS) - PHIREF(I))**2                        CSETA
      AS=-0.09*ETAREF(I)/PSMPRS                                         CSETA
      AC=-0.20*ETAREF(I)/PCMPRS                                         CSETA
      BS= -2.0*PHIREF(I)*AS                                             CSETA
      BC= -2.0*PHIREF(I)*AC                                             CSETA
      CS= ETAREF(I) + AS*PHIREF(I)**2                                   CSETA
      CC= ETAREF(I) + AC*PHIREF(I)**2                                   CSETA
      DO 20  K=1,NPTS                                                   CSETA
      IF(PHIDES(I,J,K) - PHIREF(I)) 11,12,13                            CSETA
```

```
   11 ETADES(I,J,K) = (AS*PHIDES(I,J,K) + BS)*PHIDES(I,J,K) + CS
      GO TO 20
   12 ETADES(I,J,K)= ETAREF(I)
      GO TO 20
   13 ETADES(I,J,K)=(AC*PHIDES(I,J,K)+BC)*PHIDES(I,J,K)+CC+((((PHIDES(I,
     XJ,K)-PHIREF(I))**3.0)/((PHIDES(I,J,NPTS)-PHIREF(I))**3.0))*.20*RAM
     X*ETAREF(I))
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      SUBROUTINE CSPSI(XWN,LORS)
C *** SUBROUTINE CSPSI CALCULATES PRESSURE COEFICIENTS FOR INPUT FLOW
C     COEFICIENTS
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR
     X(12,9),D2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)
     *,PSI4(12,2,8),PSI5(12,2,8)
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
     X,XAR,XMET,XSTM
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE
      J=1
      DO 100 K=1,NPTS
      I=1
      TT(I) = TO
      PT(I) = PO
      VZ2=VZ2M(I,J)*PHIDES(I,J,K)/PHIREF(I)
      VT2=VZ2*TAN(DB2M(I,1))
      VT2R=UM2(I)-VT2
      B2MR=ATAN2(VT2R,VZ2)
      B2M=DB2M(I,1)
   10 VZ3M(I,J) = VZ2M(I,J)*PHIDES(I,J,K)/PHIREF(I)
      V2MR = VZ3M(I,J)/COS(B2MR)
      BET3MR(I,J) = DB3MR(I,1)
      VT2M = VZ3M(I,J)*TAN(B2M)
      V2S = VT2M**2 + VZ3M(I,J)**2
      RHOT = PT(I)/(TT(I)*RG)
      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))**GF1REF(I)
      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
      TS = TT(I)
      ID = 0
   11 VT3M = UM3(I) - VZ3M(I,J)*TAN(BET3MR(I,J))
      CP=CPFM(TS)
      DT = (UM3(I)*VT3M - UM2(I)*VT2M)/(GJ*CP)
      TRA = (DT + TT(I))/TT(I)
      PTA3 = PT(I)*(1.0 + ETADES(I,J,K)*(TRA - 1.0))**GF2
      TTA3 = DT + TT(I)
      RHOT = PTA3/(TTA3*RG)
      V3S = VT3M**2 + VZ3M(I,J)**2
      V3M=SQRT(V3S)
      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3))**GF1
```

```
      TS = TTA3*(RHOS/RHOT)**GM1
      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
      IF (TRA.GE.1.0) GO TO 12
      DT = 0.0
      GO TO  13
   12 ID = ID + 1
      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN FLOW
C     COEFICIENT
      IF(LORS.EQ.1) CALL CSDEV(SPEEDF,XWN,V3MR,V2MR,V3DV2R(I),I,FK)
      IF(LORS.EQ.2) CALL CSDEVL(SPEEDF,XWN,V3MR,V2MR,V3DV2R(I),I,FK)
      IF (DRDEVP.EQ.1.0)
     XDB3MRP(I,K)=-(FK/RAD)*(V3MR/V2MR-V3DV2R(I))
      BET3MR(I,J) = DB3MR(I,1) + DB3MRP(I,K)
      IF ((ABS(WCAL-DESFLC)/WCAL).GT.0.005) GO TO 11
      DUMY=ETADES(I,J,K)
      IF(LORS.EQ.1)
     $CALL CSETA1 (I,J,K,XWN,PHIDES(I,J,K),PHIREF(I),DUMY)
      IF(LORS.EQ.2) CALL CSETAL(I,J,K,XWN,PHIREF(I),PHIDES(I,J,K),
     $DUMY,ETAREF(I))
   13 PSIDES(I,J,K) = GJ*CP*DT*DUMY/UT3(I)**2
      DV3DV2 = V3DV2R(I)
      FV3DV2 = V3MR/V2MR
      IF(I.EQ.NSTA) GO TO 100
      B2M=DB2M(I+1,1)
  303 VZ2=VZ3M(I,J)
  301 V2M=VZ2/COS(B2M)
      V2MS=V2M**2
      RHOT=PTA3/(TTA3*RG)
      RHOS=RHOT*(1.0-V2MS/(G2J*CPREF(I+1)*TTA3))**GF1REF(I+1)
      VZ2C=DESFLC/(RHOS*AREA2(I+1))
      IF((ABS(VZ2-VZ2C)/VZ2).LT.0.005) GO TO 300
      VZ2=(VZ2+VZ2C)/2.0
      GO TO 301
  300 IF(LORS.EQ.1) CALL CSDEVS(XWN,V2M,V3M,V2V3(I),I,FK)
      IF(LORS.EQ.2) CALL CDEVSL(XWN,V2M,V3M,V2V3(I),I,FK)
      DEVIS=-(FK/RAD)*(V2M/V3M-V2V3(I))
      B2MC=DB2M(I+1,1)+DEVIS
      IF((ABS(B2M-B2MC)/B2M).LT.0.005) GO TO 302
      B2M=(B2M+B2MC)/2.0
      GO TO 303
  302 VT2R=UM2(I+1)-VZ2*TAN(B2M)
      B2MR=ATAN2(VT2R,VZ2M)
      I=I+1
      IF(I.LE.NSTA) GO TO 10
  100 CONTINUE
      RETURN
      END
      SUBROUTINE CSDEVS(XW,V2M,V3M,V2V3S,I,FK)
      T1=V2M/V3M-V2V3S
      FK=26.0+0.12/T1
      RETURN
      END
      SUBROUTINE CDEVSL(XW,V2M,V3M,V2V3S,I,FK)
      T1=V2M/V3M-V2V3S
      FK=26.0+0.12/T1
      RETURN
      END
      SUBROUTINE CSDEV(SPEEDF,XW,V3MR,V2MR,V3DV2,I,FK)
      T1=V3MR/V2MR-V3DV2
      IF(I.EQ.1.AND.T1.LT.0.0) GO TO 200
      IF(I.EQ.2.AND.T1.LT.0.0) GO TO 201
      IF(I.GE.3.AND.T1.LT.0.0) GO TO 202
      IF( T1.GT.0.0) GO TO 203
  200 A1=-3.15
      B1=-0.21
      AFO=30.0
      IF(T1.LT.-0.05) T1=-0.05
      GO TO 204
```

```
201 A1=-3.70                                                            CSDEV
    B1=-0.11                                                            CSDEV
    AFO=25.0                                                            CSDEV
    IF(T1.LT.-0.05) T1=-0.05                                            CSDEV
    GO TO 204                                                           CSDEV
202 A1=-3.73                                                            CSDEV
    B1=-0.13                                                            CSDEV
    AFO=30.0                                                            CSDEV
    IF(T1.LT.-0.05) T1=-0.05                                            CSDEV
    GO TO 204                                                           CSDEV
203 A1=1.80                                                             CSDEV
    B1=0.23                                                             CSDEV
    AFO=-10.0                                                           CSDEV
    IF(T1.GT.0.05) T1=0.05                                              CSDEV
204 T2=A1*XW+B1                                                         CSDEV
    FK=T2/T1+AFO                                                        CSDEV
    DK=0.0                                                              CSDEV
    IF (T1.GT.0.0) GO TO 205                                            CSDEV
    ISPD=IFIX(SPEEDF*100.0)                                             CSDEV
    IF (ISPD.EQ.70.OR.ISPD.EQ.69)  DK=DELK70(I,T1)                      CSDEV
    IF (ISPD.EQ.80.OR.ISPD.EQ.79)  DK=DELK80(I,T1)                      CSDEV
    IF (ISPD.EQ.90.OR.ISPD.EQ.89)  DK=0.0                               CSDEV
    IF (ISPD.EQ.100.OR.ISPD.EQ.99) DK=DELK10(I,T1)                      CSDEV
205 FK = FK-DK                                                          CSDEV
    RETURN                                                              CSDEV
    END                                                                 CSDEV
    SUBROUTINE CSDEVL(SPEEDF,XW,V3MR,V2MR,V3DV2,I,FK)                   CSDEVL
    T1=V3MR/V2MR-V3DV2                                                  CSDEVL
    IF(I.EQ.1.AND.T1.LT.0.0) GO TO 200                                  CSDEVL
    IF(I.EQ.2.AND.T1.LT.0.0) GO TO 201                                  CSDEVL
    IF(I.GE.3.AND.T1.LT.0.0) GO TO 202                                  CSDEVL
    IF( T1.GT.0.0) GO TO 203                                            CSDEVL
200 A1=-3.15                                                            CSDEVL
    B1=-0.21                                                            CSDEVL
    AFO=30.0                                                            CSDEVL
    IF(T1.LT.-0.05) T1=-0.05                                            CSDEVL
    GO TO 204                                                           CSDEVL
201 A1=-3.70                                                            CSDEVL
    B1=-0.11                                                            CSDEVL
    AFO=25.0                                                            CSDEVL
    IF(T1.LT.-0.05) T1=-0.05                                            CSDEVL
    GO TO 204                                                           CSDEVL
202 A1=-3.73                                                            CSDEVL
    B1=-0.13                                                            CSDEVL
    AFO=30.0                                                            CSDEVL
    IF(T1.LT.-0.05) T1=-0.05                                            CSDEVL
    GO TO 204                                                           CSDEVL
203 A1=1.80                                                             CSDEVL
    B1=0.23                                                             CSDEVL
    AFO=-10.0                                                           CSDEVL
    IF(T1.GT.0.05) T1=0.05                                              CSDEVL
204 T2=A1*XW+B1                                                         CSDEVL
    FK=T2/T1+AFO                                                        CSDEVL
    DK = 0.0                                                            CSDEVL
    IF (T1.GT.0.0) GO TO 205                                            CSDEVL
    ISPD = IFIX(SPEEDF*100.0)                                           CSDEVL
    IF (ISPD.EQ.70.OR.ISPD.EQ.69) DK = DELK70(I,T1)                     CSDEVL
    IF (ISPD.EQ.80.OR.ISPD.EQ.79) DK = DELK80(I,T1)                     CSDEVL
    IF (ISPD.EQ.90.OR.ISPD.EQ.89) DK = 0.0                              CSDEVL
    IF (ISPD.EQ.100.OR.ISPD.EQ.99) DK = DELK10(I,T1)                    CSDEVL
205 FK = FK - DK                                                        CSDEVL
    RETURN                                                              CSDEVL
    END                                                                 CSDEVL
    FUNCTION  DELK70(I,T1)                                              DELK70
    IF (I.EQ.1) GO TO 1                                                 DELK70
    IF (I.EQ.2) GO TO 2                                                 DELK70
    IF (I.EQ.3) GO TO 3                                                 DELK70
    IF (I.EQ.4) GO TO 4                                                 DELK70
    IF (I.EQ.5) GO TO 5                                                 DELK70
    IF (I.EQ.6) GO TO 6                                                 DELK70
```

```
    1 A = -140625.0
      B = -262500.0
      C = -12219.0
      D = 311.0
      E = 39.0
      GO TO 100
    2 A = -312500.0
      B = -35417.0
      C = 1875.0
      D = 399.0
      E = 24.0
      GO TO 100
    3 A = -2369792.0
      B = -439583.0
      C = -21568.0
      D = 199.0
      E = 36.0
      GO TO 100
    4 A =-1953125.0
      B = -377083.0
      C = -20109.0
      D = 93.0
      E = 33.0
      GO TO 100
    5 A = -1953125.0
      B = -377083.0
      C = -20109.0
      D = 93.0
      E = 33.0
      GO TO 100
    6 A = -1953125.0
      B = -377083.0
      C = -20109.0
      D = 93.0
      E = 33.0
  100 DELK70=A*T1**4+B*T1**3+C*T1**2+D*T1+E
      RETURN
      END
      FUNCTION DELK80(I,T1)
      IF (I.EQ.1) GO TO 1
      IF (I.EQ.2) GO TO 2
      IF (I.EQ.3) GO TO 3
      IF (I.EQ.4) GO TO 4
      IF (I.EQ.5) GO TO 5
      IF (I.EQ.6) GO TO 6
    1 A = -1093750.0
      B = -227083.0
      C =  -14094.0
      D = -87.0
      E = 19.0
      GO TO 100
    2 A = -546875.0
      B = -95833.0
      C = -3703.0
      D = 150.0
      E = 15.0
      GO TO 100
    3 A = -859375.0
      B = -152083.0
      C = -6328.0
      D = 200.0
      E = 19.0
      GO TO 100
    4 A = -520833.0
      B = -83333.0
      C = -1229.0
      D = 393.0
      E = 23.0
      GO TO 100
    5 A = 572917.0
```

```
      B = 183333.0
      C = 22052.0
      D = 1217.0
      E = 33.0
      GO TO 100
    6 A = 1953124.0
      B= 504167.0
      C = 47047.0
      D = 1920.0
      E = 38.0

  100 DELK80=A*T1**4+B*T1**3+C*T1**2+D*T1+E
      RETURN
      END
      FUNCTION DELK10(I,T1)
      IF (I.EQ.1) GO TO 1
      IF (I.EQ.2) GO TO 2
      IF (I.EQ.3) GO TO 3
      IF (I.EQ.4) GO TO 4
      IF (I.EQ.5) GO TO 5
      IF (I.EQ.6) GO TO 6
    1 A = -755208.0
      B = -189583.0
      C = -19932.0
      D = -1161.0
      E = -38.0
      GO TO 100
    2 A = - 234375.0
      B = -66667.0
      C = -7891.0
      D = -528.0
      E = -20.0
      GO TO 100
    3 A = -1927083.0
      B = - 487500.0
      C = -44948.0
      D = -1921.0
      E = -42.0
      GO TO 100
    4 A = -1510417.0
      B = -350000.0
      C = -30865.0
      D = -1390.0
      E = -36.0
      GO TO 100
    5 A = -4479167.0
      B = -1050000.0
      C = -89356.0
      D = -3420.0
      E = -60.0
      GO TO 100
    6 A = -1562500.0
      B = -393750.0
      C = -38375.0
      D = -1826.0
      E = -42.0

  100 DELK10=A*T1**4+B*T1**3+C*T1**2+D*T1+E
      RETURN
      END
      FUNCTION DPHI(I,ISPD)
      IF (I.EQ.1) GO TO 1
      IF (I.EQ.2) GO TO 2
      IF (I.GE.3) GO TO 3
    1 IF (ISPD.EQ.70.OR.ISPD.EQ.69) DPHI=-0.0357
      IF (ISPD.EQ.80.OR.ISPD.EQ.79) DPHI=-0.0357
      IF (ISPD.EQ.90.OR.ISPD.EQ.89) DPHI=0.0
      IF (ISPD.EQ.100.OR.ISPD.EQ.99) DPHI=0.0357
      GO TO 100
    2 IF (ISPD.EQ.70.OR.ISPD.EQ.69) DPHI = -0.0286
```

```
      IF (ISPD.EQ.80.OR.ISPD.EQ.79) DPHI = -0.0286                      DPHI
      IF (ISPD.EQ.90.OR.ISPD.EQ.89) DPHI = 0.0                          DPHI
      IF (ISPD.EQ.100.OR.ISPD.EQ.99) DPHI = 0.0286                      DPHI
      GO TO 100                                                         DPHI
    3 IF (ISPD.EQ.70.OR.ISPD.EQ.69) DPHI = -0.0333                      DPHI
      IF (ISPD.EQ.80.OR.ISPD.EQ.79) DPHI = -0.0333                      DPHI
      IF (ISPD.EQ.90.OR.ISPD.EQ.89) DPHI = 0.0                          DPHI
                                                                        DPHI
      IF (ISPD.EQ.100.OR.ISPD.EQ.99) DPHI = 0.0333                      DPHI
  100 RETURN                                                            DPHI
      END                                                               DPHI
      SUBROUTINE CSETA1(I,J,K,XW,PHID,PHIR,ETAD)                        CSETAD
      IF(I.EQ.1.AND.XW.LT.0.04) Y=0.4575*XW                             CSETAD
      IF(I.EQ.1.AND.XW.GE.0.04) Y=0.12*XW+0.0135                        CSETAD
      T3=PHID-PHIR                                                      CSETAD
      IF(I.EQ.1) GO TO 304                                              CSETAD
      IF(I.EQ.2.AND.T3.LT.-0.08) GO TO 300                              CSETAD
      IF(I.EQ.2.AND.T3.GE.-0.08) GO TO 301                              CSETAD
      IF(I.GE.3) GO TO 302                                              CSETAD
  300 A=0.0                                                             CSETAD
      B=0.50*XW                                                         CSETAD
      IF(XW.GT.0.04) A=-0.982*XW+0.0393                                 CSETAD
      IF(XW.GT.0.04) B=0.02                                             CSETAD
      GO TO 303                                                         CSETAD
  301 A=3.125*XW                                                        CSETAD
      B=0.7375*XW                                                       CSETAD
      IF(XW.GT.0.04) A=0.125                                            CSETAD
      IF(XW.GT.0.04) B=0.09*XW+0.026                                    CSETAD
      GO TO 303                                                         CSETAD
  302 A=5.0*XW                                                          CSETAD
      B=0.625*XW                                                        CSETAD
      IF(XW.GT.0.04) A=0.80*XW+0.168                                    CSETAD
      IF(XW.GT.0.04) B=0.1455*XW+0.0192                                 CSETAD
      IF(T3.LT.-0.004) T3=-0.04                                         CSETAD
  303 Y=A*T3+B                                                          CSETAD
  304 ETAD=ETAD-Y                                                       CSETAD
      RETURN                                                            CSETAD
      END                                                               CSETAD
      SUBROUTINE CSETAL(I,J,K,XW,PHID,PHIR,ETAD,ETADD)                  CSETAL
      T=PHIR/PHID                                                       CSETAL
      IF(I.EQ.1.OR.I.EQ.2) GO TO 10                                     CSETAL
      IF(I.EQ.3) GO TO 20                                               CSETAL
      GO TO 30                                                          CSETAL
   10 IF(T.LT.0.88.AND.XW.LT.0.44) Y=1.25*XW                            CSETAL
      IF(T.LT.0.88.AND.XW.GE.0.04) Y=0.4364*XW+0.032544                 CSETAL
      IF(T.GE.0.88.AND.XW.LT.0.04) Y=-27.0*(T-0.934)**2+1.1392*XW+0.0787 CSETAL
      IF(T.GE.0.88.AND.XW.GE.0.04) Y=-27.0*(T-0.934)**2+0.5067*XW+0.1040 CSETAL
      GO TO 40                                                          CSETAL
   20 IF(T.LT.0.87.AND.XW.LT.0.04) Y=1.050*XW                           CSETAL
      IF(T.LT.0.87.AND.XW.GE.0.04) Y=0.2333*XW+0.033                    CSETAL
      IF(T.GE.0.87.AND.XW.LT.0.04) Y=-11.90*(T-0.940)**2+1.0158*XW+0.058 CSETAL
     $3                                                                 CSETAL
      IF(T.GE.0.87.AND.XW.GE.0.04) Y=-11.9*(T-0.94)**2+0.2733*XW+0.0880 CSETAL
      GO TO 40                                                          CSETAL
   30 IF(T.LT.0.92.AND.XW.LT.0.04) Y=0.450*XW                           CSETAL
      IF(T.LT.0.92.AND.XW.GE.0.04) Y=0.09867*XW+0.0142                  CSETAL
      IF(T.GE.0.92.AND.XW.LT.0.04) Y=3.215*XW*T-2.5075*XW               CSETAL
      IF(T.GE.0.92.AND.XW.GE.0.04) Y=(0.440*XW+0.1110)*T-0.3325*XW-     CSETAL
     $0.0870                                                            CSETAL
   40 IF(XW.LT.0.000000001) Y=0.0                                       CSETAL
      ETAD=ETAD-Y*ETADD                                                 CSETAL
      RETURN                                                            CSETAL
      END                                                               CSETAL
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ CSPSD
      SUBROUTINE CSPSD                                                  CSPSD
C *** SUBROUTINE CSPSD ALTERS PRESSURE RISE COEFICIENTS FOR OFF DESIGN  CSPSD
C     SPEEDS                                                            CSPSD
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),    CSPSD
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      CSPSD
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9 CSPSD
```

```
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),          CSPSD
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),   CSPSD
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)   CSPSD
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)    CSPSD
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(     CSPSD
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12   CSPSD
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)          CSPSD
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR   CSPSD
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)     CSPSD
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)                          CSPSD
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)                                CSPSD
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)             CSPSD
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)                CSPSD
     *,PSI4(12,2,8),PSI5(12,2,8)                                           CSPSD
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                        CSPSD
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                         CSPSD
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)             CSPSD
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA   CSPSD
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                          CSPSD
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP       CSPSD
     X,XAR,XMET,XSTM                                                       CSPSD
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                         CSPSD
      DO 100 J=1,NSPE                                                      CSPSD
      I = 1                                                                CSPSD
      TT(I) = TO                                                           CSPSD
      PT(I) = PO                                                           CSPSD
   10 VZ3M(I,J) = VZ2M(I,1)*SPEEDF                                         CSPSD
      V2MR = VZ3M(I,J)/COS(DB2MR(I,1))                                     CSPSD
      BET3MR(I,J) = DB3MR(I,1)                                             CSPSD
      ID = 0                                                               CSPSD
      VT2M= VZ2M(I,1)*SPEEDF*  TAN(DB2M(I,1))                              CSPSD
      V2S = VT2M**2 + VZ3M(I,J)**2                                         CSPSD
      RHOT = PT(I)/(TT(I)*RG)                                              CSPSD
      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))**GF1REF(I)              CSPSD
      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)                                     CSPSD
      TS = TT(I)                                                           CSPSD
   11 VT3M = UM3(I)*SPEEDF - VZ3M(I,J)*TAN(BET3MR(I,J))                    CSPSD
      CP=CPFM(TS)                                                          CSPSD
      DT = (UM3(I)*VT3M - UM2(I)*VT2M)/(GJ*CP)*SPEEDF                      CSPSD
      TRA =  (DT + TT(I))/TT(I)                                            CSPSD
      PTA3 = PT(I)*(1.0 + ETAREF(I)*(TRA - 1.0))**GF2                      CSPSD
      TTA3 = DT + TT(I)                                                    CSPSD
      RHOT = PTA3/(TTA3*RG)                                                CSPSD
      V3S = VT3M**2 + VZ3M(I,J)**2                                         CSPSD
      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3))**GF1                           CSPSD
      TS = TTA3*(RHOS/RHOT)**GM1                                           CSPSD
      WCAL = RHOS*AREA3(I)*VZ3M(I,J)                                       CSPSD
      IF (I.NE.1) GO TO 12                                                 CSPSD
      DVZ3M = VZ3M(I,J)                                                    CSPSD
   12 CONTINUE                                                             CSPSD
      ID = ID + 1                                                          CSPSD
      VZ3M(I,J)=DESFLC/(RHOS*AREA3(I))                                     CSPSD
      V3MR=VZ3M(I,J)/COS(BET3MR(I,J))                                      CSPSD
      IF(DRDEVN.EQ.1.0)                                                    CSPSD
     XDB3MRN(I,J) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))                   CSPSD
      BET3MR(I,J) = DB3MR(I,1) + DB3MRN(I,J)                               CSPSD
      IF ((ABS(WCAL-DESFLC)/WCAL).GT.0.005) GO TO 11                       CSPSD
      DPSIS(I,J) = GJ*CP*DT*ETAREF(I)/(UT3(I)*SPEEDF)**2 - PSIREF(I)       CSPSD
      DPSIS(I,J) = DPSIS(I,J) - DPSIS(I,1)                                 CSPSD
      I= I + 1                                                             CSPSD
      IF (I.LE.NSTA) GO TO 10                                              CSPSD
  100 CONTINUE                                                             CSPSD
      RETURN                                                               CSPSD
      END                                                                  CSPSD
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  CSPAN
      SUBROUTINE CSPAN                                                     CSPAN
C *** SUBROUTINE CSPAN ALTERS FLOW AND PRESSURE RISE COEFICIENTS FOR       CSPAN
C     BLADE RESET                                                          CSPAN
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),       CSPAN
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),         CSPAN
```

```
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)
     *,PSI4(12,2,8),PSI5(12,2,8)
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
     X,XAR,XMET,XSTM
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE
      J=1
      I=1
      TT(I)= TO
      PT(I)= PO
   90 TS= TT(I)
      DPHIA(I) = 0.0
      DPSIA(I) = 0.0
      DETA(I) = 0.0
      IF((CB2M(I) + CB2MR(I) + CB3MR(I)).EQ.0.00) GO TO 93
      BET2M(I,J)=  DB2M(I,J) + CB2M(I)
      BAT2MR(I,J)=  DB2MR(I,J) + CB2MR(I)
      BET3MR(I,J) =  DB3MR(I,J) + CB3MR(I)
      VZ2M(I,J)= UM2(I)/(TAN(BET2M(I,J))+ TAN(BAT2MR(I,J)))
      V2MR = VZ2M(I,J)/COS(BAT2MR(I,J))
C *** CHANGE IN FLOW COEFICIENT FOR RESET
      DPHIA(I)= VZ2M(I,J)/UT2(I) - PHIREF(I)
      VZ3M(I,J)= VZ2M(I,J)
      VT2M= VZ2M(I,J)*TAN(BET2M(I,J))
      V2S = VT2M**2 + VZ3M(I,J)**2
      RHOT = PT(I)/(TT(I)*RG)
      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))**GF1REF(I)
      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
      FLOCAL(I,J) = DESFLC
   92 VT3M= UM3(I) - VZ3M(I,J) *TAN(BET3MR(I,J))
      CP=CPFM(TS)
      DT= (UM3(I) * VT3M - UM2(I)*VT2M)/(GJ*CP)
      TRA  = (DT + TT(I))/TT(I)
      PTA3   = PT(I)*(1.0 + ETAREF(I)*(TRA  -1.0))**GF2
      TTA3   = DT + TT(I)
      RHOT= PTA3   /(TTA3   *RG)
      V3S = VT3M**2 + VZ3M(I,J)**2
      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3   ))**GF1
      TS = TTA3   *(RHOS/RHOT)**GM1
      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR BLADE RESET
      IF (DRDEVG.EQ.1.0)
     XDB3MRG(I) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
      BET3MR(I,J) = DB3MR(I,J) + CB3MR(I) + DB3MRG(I)
      IF ((ABS(WCAL-DESFLC)/WCAL).GT.0.005) GO TO 92
C *** CHANGE IN PRESSURE RISE COEFICIENT FOR RESET
      DPSIA(I) = GJ*CP*DT/(UT3(I)*UT3(I))*ETAREF(I) -  PSIREF(I)
   93 I = I+1
      IF (I.LE.NSTA) GO TO 90
      RETURN
      END
```

```
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ CSOUPT
      SUBROUTINE CSOUPT(FAIO,ISTAGE,FLOW1,ALFA1,BETA1,BETA2,                   CSOUPT
     XVZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2)                                  CSOUPT
C     PERFORMANCE PARAMETERS                                                   CSOUPT
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                CSOUPT
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)               CSOUPT
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)              CSOUPT
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                                      CSOUPT
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                               CSOUPT
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                               CSOUPT
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)              CSOUPT
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)              CSOUPT
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI             CSOUPT
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT             CSOUPT
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                                 CSOUPT
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                             CSOUPT
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)                   CSOUPT
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                         CSOUPT
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)              CSOUPT
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),           CSOUPT
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),             CSOUPT
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9       CSOUPT
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),              CSOUPT
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),       CSOUPT
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)       CSOUPT
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)        CSOUPT
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),   RK2M(12), CB2M(12), CB2MR(        CSOUPT
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12       CSOUPT
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)              CSOUPT
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR       CSOUPT
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)         CSOUPT
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)                              CSOUPT
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)                                    CSOUPT
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)                 CSOUPT
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)                    CSOUPT
     *,PSI4(12,2,8),PSI5(12,2,8)                                               CSOUPT
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                            CSOUPT
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                             CSOUPT
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)                 CSOUPT
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA       CSOUPT
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                              CSOUPT
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP           CSOUPT
     X,XAR,XMET,XSTM                                                           CSOUPT
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                             CSOUPT
      FLOWIN=FLOW1                                                             CSOUPT
      DFLOW=FLOWIN                                                             CSOUPT
      FLOWFI=FLOWIN                                                            CSOUPT
      IF (UNITS.NE.1.0) GO TO 81                                               CSOUPT
      FLOWIN = FLOWIN/0.453592                                                 CSOUPT
      DFLOW  =  DFLOW/0.453592                                                 CSOUPT
      FLOWFI = FLOWFI/0.453592                                                 CSOUPT
   81 CONTINUE                                                                 CSOUPT
      JS=1                                                                     CSOUPT
      DO 82 J=1,NSPE                                                           CSOUPT
      IF (SPEEDF.EQ.PCTSPD(J)) JS=J                                            CSOUPT
   82 CONTINUE                                                                 CSOUPT
C *** CALCULATE THE OUTPUT                                                     CSOUPT
      I=ISTAGE                                                                 CSOUPT
      TT(I)=TG(1)                                                              CSOUPT
      PT(I)=P(1)                                                               CSOUPT
      WTFLOW = FLOWIN                                                          CSOUPT
      RHOT= PT(I)/(TT(I)*RG)                                                   CSOUPT
      TS= TT(I)                                                                CSOUPT
      RHOS= RHOT                                                               CSOUPT
      RHOW=62.3                                                                CSOUPT
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)                                CSOUPT
      WTFLOW = WTFLOW - FLOWIN*BLEED(I,JS)                                     CSOUPT
      U2 = UT2(I)*SPEEDF                                                       CSOUPT
      U3 = UT3(I)*SPEEDF                                                       CSOUPT
      UMM2 = UM2(I)*SPEEDF                                                     CSOUPT
```

```
      UMM3 = UM3(I)*SPEEDF
  100 VZ=WTFLOW/(RHOSM*AREA2(I))
      V= VZ/COS(BET2M(I,1))
      CP=CPFM(TS)
      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))**GF1
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)
      IF ((V*V).GT.(G2J*CP*TT(I))) GO TO 113
      TS= TT(I)*(RHOS/RHOT)**GM1
      RHOS1=RHOS
      TS1=TS
      PS1=PT(I)*(TT(I)/TS1)**(-GF2)
      WCAL=RHOSM*VZ*AREA2(I)
      IF((ABS(WCAL-WTFLOW)/WCAL).GT.0.005)  GO TO 100
      PHIC = VZ/U2
      IF(PHIC.GT.PHI(I,JS,NPTS)) GO TO 120
      DO 200 I=1,NSTA
      DO 200 J=1,NSPE
      DO 200 K=1,NPTS
      PSI(I,J,K)=PSI1(I,J,K)
      IF(XW(1).GT.0.0.AND.XW(1).LE.0.05) PSI(I,J,K)=PSI2(I,J,K)
      IF(XW(1).GT.0.05.AND.XW(1).LE.0.10)PSI(I,J,K)=PSI3(I,J,K)
      IF(XW(1).GT.0.10.AND.XW(1).LE.0.15)PSI(I,J,K)=PSI4(I,J,K)
      IF(XW(1).GT.0.15) PSI(I,J,K)=PSI5(I,J,K)
  200 CONTINUE
      I=ISTAGE
      DO 130  K=2,NPTS
      IF(PHIC-PHI(I,JS,K))  140,150,130
  130 CONTINUE
      K= NPTS
  140 PSIC=(PSI(I,JS,K)-PSI(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
     1      (PHI(I,JS,K)-PHI(I,JS,K-1)) + PSI(I,JS,K-1)
      ETAC=(ETA(I,JS,K)-ETA(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
     1      (PHI(I,JS,K)-PHI(I,JS,K-1)) + ETA(I,JS,K-1)
      GO TO 160
  150 PSIC= PSI(I,JS,K)
      ETAC= ETA(I,JS,K)
  160 CONTINUE
      CALL CSETA1(I,J,K,XW(1),PHIC,PHIREF(I),ETAC)
      PR(I) = (1.0 + PSIC*U3*U3/    (GJ*CP*TT(I)))**GF2
      TAU = PSIC/ETAC
      TR(I)= 1.0 + (PR(I)**GF3-1.0)/ETAC
      TT(I+1)= TT(I)*TR(I)
      PT(I+1)= PT(I) *PR(I)
      TRO(I)= TT(I+1)/TO
      PRO(I)= PT(I+1)/PO
      GF3S = GF3
      GF30= (GF3 + GF3S)/2.0
      ETAO(I)= (PRO(I)**GF30 - 1.0)/(TRO(I) - 1.0)
      VT2M = VZ * TAN(BET2M(I,1))
      VT2MR = UMM2    - VT2M
      BAT2MR(I,JS)= ATAN2(VT2MR,VZ)
      RINCM(I)= BAT2MR(I,JS) * RAD - RK2M(I)
      V2MR= VZ/COS(BAT2MR(I,JS))
      RHOT= PT(I+1)/(TT(I+1)*RG)
      TS= TT(I+1)
      RHOS= RHOT
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)
  161 VZ3M(I,JS)=WTFLOW/(RHOSM*AREA3(I))
      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UMM2  *VT2M)/UMM3
      VS= VZ3M(I,JS)**2 + VT3M**2
      CP=CPFM(TS)
      RHOS= RHOT*(1.0-VS/(G2J*CP*TT(I+1)))**GF1
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)
      IF((VS).GT.(G2J*CP*TT(I+1))) GO TO 113
      TS= TT(I+1) * (RHOS/RHOT)**GM1
      RHOS2=RHOS
      TS2=TS
      PS2=PT(I+1)*(TT(I+1)/TS2)**(-GF2)
      WCAL=RHOSM*AREA3(I)*VZ3M(I,JS)
      IF(ABS(WCAL-WTFLOW).GT.0.005)  GO TO 161
```

```
      BET3M(I,JS) = ATAN2(VT3M,VZ3M(I,JS))                              CSOUPT
      SINCM(I) = BET3M(I,JS)*RAD - SK2M(I)                              CSOUPT
      VT3MR = UMM3   - VT3M                                             CSOUPT
      BET3MR(I,JS)= ATAN2(VT3MR,VZ3M(I,JS))                             CSOUPT
      V3MR = VZ3M(I,JS)/COS(BET3MR(I,JS))                               CSOUPT
      RDFM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +  CSOUPT
     XRM2(I))/RSOLM(I)/V2MR                                             CSOUPT
      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW*0.453592                        CSOUPT
      RDEV(I)=BET3MR(I,JS)*RAD-RK3M(I)                                  CSOUPT
      BAT2MR(I,JS)=BAT2MR(I,JS)*RAD                                     CSOUPT
      BET3MR(I,JS)=BET3MR(I,JS)*RAD                                     CSOUPT
      RDEF(I)=BAT2MR(I,JS)-BET3MR(I,JS)                                 CSOUPT
      SOA1=SQRT(GAMMA*RG*G*TS1)                                         CSOUPT
      SOA2=SQRT(GAMMA*RG*G*TS2)                                         CSOUPT
      AM2=V/SOA1                                                        CSOUPT
      AM3=SQRT(VS)/SOA2                                                 CSOUPT
      AM2R=V2MR/SOA1                                                    CSOUPT
      AM3R=V3MR/SOA2                                                    CSOUPT
      PRATIO=PR(I)                                                      CSOUPT
      TRATIO=TR(I)                                                      CSOUPT
      FAI1=PHIC                                                         CSOUPT
      FAI2=VZ3M(I,JS)                                                   CSOUPT
      VZ1=VZ                                                            CSOUPT
      UTIPG(I)=U2                                                       CSOUPT
      P(1)=PT(I)                                                        CSOUPT
      P(2)=PT(I+1)                                                      CSOUPT
      P(3)=P(2)                                                         CSOUPT
      TG(1)=TT(I)                                                       CSOUPT
      TG(2)=TT(I+1)                                                     CSOUPT
      TG(3)=TG(2)                                                       CSOUPT
      DELTG=TG(2)-TG(1)                                                 CSOUPT
      DELTW=(TG(2)-TG(1))*CP                                            CSOUPT
      RHOG(1)=RHOS1                                                     CSOUPT
      RHOG(2)=RHOS2                                                     CSOUPT
      VZ2=VZ3M(I,JS)                                                    CSOUPT
      V1=V                                                              CSOUPT
      V2=SQRT(VS)                                                       CSOUPT
      W1=V2MR                                                           CSOUPT
      W2=V3MR                                                           CSOUPT
      VS1=VT2M                                                          CSOUPT
      VS2=VT3M                                                          CSOUPT
      WS1=VT2MR                                                         CSOUPT
      WS2=VT3MR                                                         CSOUPT
      ASPED1=SOA1                                                       CSOUPT
      ASPED2=SOA2                                                       CSOUPT
      AMAC1=AM2                                                         CSOUPT
      AMAC2=AM3                                                         CSOUPT
      AMACH1=AM2R                                                       CSOUPT
      AMACH2=AM3R                                                       CSOUPT
      FAI1=PHIC                                                         CSOUPT
      FAI2=VZ3M(I,JS)/U3                                                CSOUPT
      AAA1=SAREA(I)                                                     CSOUPT
      AAA2=SAREAS(I)                                                    CSOUPT
      ALFA1=BET2M(I,1)*RAD                                              CSOUPT
      ALFA2=BET3M(I,JS)*RAD                                             CSOUPT
      ALFA3=0.0                                                         CSOUPT
      IF(I.LT.NSTA) ALFA3=BET2M(I+1,1)*RAD                              CSOUPT
      BETA1=BAT2MR(I,JS)                                                CSOUPT
      BETA2=BET3MR(I,JS)                                                CSOUPT
      AINCIR=RINCM(I)                                                   CSOUPT
      AINCIS=SINCM(I)                                                   CSOUPT
      ADEVIR=RDEV(I)                                                    CSOUPT
C *** WRITE THE OUTPUT                                                  CSOUPT
      WRITE(6,404) FAIO,ISTAGE                                          CSOUPT
  404 FORMAT(1H1,1X,≠********************  ≠,1X,                        CSOUPT
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F5.3,1X,≠(STAGE=≠,I2,1X,           CSOUPT
     $≠)≠,2X,≠********************≠)                                    CSOUPT
       WRITE(6,401) PRATIO,TRATIO,ETAC                                  CSOUPT
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,              CSOUPT
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,                      CSOUPT
```

```
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)                            CSOUPT
      WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)                                CSOUPT
  402 FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,                    CSOUPT
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,                                       CSOUPT
     $6X,≠ROTOR SPEED=≠,F7.2,/)                                          CSOUPT
      WRITE(6,405)                                                       CSOUPT
  405 FORMAT(1H0,24X,≠*ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*≠)     CSOUPT
      WRITE(6,406) P(1),P(2),P(3)                                        CSOUPT
  406 FORMAT(1H ,1X,≠TOTAL PRESSURE≠,10X,3(F10.4,5X))                    CSOUPT
      WRITE(6,407) PS1,PS2                                               CSOUPT
  407 FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,2(F10.4,5X))                    CSOUPT
      WRITE(6,408) TG(1),TG(2),TG(3)                                     CSOUPT
  408 FORMAT(1H ,1X,≠TOTAL TEMPERATURE(GAS)≠,3X,3(F10.4,5X))             CSOUPT
      WRITE(6,409) TS1,TS2                                               CSOUPT
  409 FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,2(F10.4,5X))            CSOUPT
      WRITE(6,410) RHOG(1),RHOG(2)                                       CSOUPT
  410 FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,2(F10.4,5X))                CSOUPT
      WRITE(6,412) VZ1,VZ2                                               CSOUPT
  412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,2(F10.4,5X))                    CSOUPT
      WRITE(6,413) V1,V2                                                 CSOUPT
  413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,2(F10.4,5X))                  CSOUPT
      WRITE(6,414) W1,W2                                                 CSOUPT
  414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))                  CSOUPT
      WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)                     CSOUPT
  415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))                       CSOUPT
      WRITE(6,416) VS1,VS2                                               CSOUPT
  416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))              CSOUPT
      WRITE(6,417) WS1,WS2                                               CSOUPT
  417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))              CSOUPT
      WRITE(6,418) ASPED1,ASPED2                                         CSOUPT
  418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,2(F10.4,5X))                    CSOUPT
      WRITE(6,419) AMAC1,AMAC2                                           CSOUPT
  419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,2(F10.4,5X))               CSOUPT
      WRITE(6,420) AMACH1,AMACH2                                         CSOUPT
  420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))               CSOUPT
      WRITE(6,421) FAI1,FAI2                                             CSOUPT
  421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,2(F10.4,5X))                   CSOUPT
      WRITE(6,422) AAA1,AAA2                                             CSOUPT
  422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,2(F10.4,5X))                         CSOUPT
      WRITE(6,423) ALFA1,ALFA2,ALFA3                                     CSOUPT
  423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))                CSOUPT
      WRITE(6,424) BETA1,BETA2                                           CSOUPT
  424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))                CSOUPT
      WRITE(6,425) AINCIR,AINCIS                                         CSOUPT
  425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))                         CSOUPT
      WRITE(6,426) ADEVIR                                                CSOUPT
  426 FORMAT(1H ,1X,≠DEVIATION≠,30X,1(F10.4,5X))                         CSOUPT
      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW/0.453592                         CSOUPT
      GO TO 111                                                          CSOUPT
  110 WRITE(6,2100) I,PHIC                                               CSOUPT
 2100 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H STALL)     CSOUPT
      GO TO 111                                                          CSOUPT
  120 WRITE(6,2110)I,PHIC                                                CSOUPT
 2110 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H CHOKE)     CSOUPT
      GO TO 113                                                          CSOUPT
  111 FLOWIN=FLOWIN+DFLOW                                                CSOUPT
      IF (FLOWIN.LE.FLOWFI) GO TO 81                                     CSOUPT
  113 CONTINUE                                                           CSOUPT
      DO 112 I=1,NSTA                                                    CSOUPT
      DO 112 J=1,NSPE                                                    CSOUPT
  112 DPSIS(I,J) = 0.0                                                   CSOUPT
      RETURN                                                             CSOUPT
      END                                                                CSOUPT
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  COUPT
      SUBROUTINE COUPT2(FAI0,ISTAGE,FLOW1,ALFA1,BETA1,BETA2,             COUPT
     XVZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2)                            COUPT
C     PERFORMANCE PARAMETERS                                             COUPT
      COMMON /PERDUE/  JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW          COUPT
     X, PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)         COUPT
     X, P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)        COUPT
```

```
      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW*0.453592
      RDEV(I)=BET3MR(I,JS)*RAD-RK3M(I)
      BAT2MR(I,JS)=BAT2MR(I,JS)*RAD
      BET3MR(I,JS)=BET3MR(I,JS)*RAD
      RDEF(I)=BAT2MR(I,JS)-BET3MR(I,JS)
      SOA1=SQRT(GAMMA*RG*G*TS1)
      SOA2=SQRT(GAMMA*RG*G*TS2)
      AM2=V/SOA1
      AM3=SQRT(VS)/SOA2
      AM2R=V2MR/SOA1
      AM3R=V3MR/SOA2
      PRATIO=PR(I)
      TRATIO=TR(I)
      FAI1=PHIC
      FAI2=VZ3M(I,JS)
      VZ1=VZ
      UTIPG(I)=U2
      P(1)=PT(I)
      P(2)=PT(I+1)
      P(3)=P(2)
      TG(1)=TT(I)
      TG(2)=TT(I+1)
      TG(3)=TG(2)
      DELTG=TG(2)-TG(1)
      DELTW=0.0
      RHOG(1)=RHOS1
      RHOG(2)=RHOS2
      VZ2=VZ3M(I,JS)
      V1=V
      V2=SQRT(VS)
      W1=V2MR
      W2=V3MR
      VS1=VT2M
      VS2=VT3M
      WS1=VT2MR
      WS2=VT3MR
      ASPED1=SOA1
      ASPED2=SOA2
      AMAC1=AM2
      AMAC2=AM3
      AMACH1=AM2R
      AMACH2=AM3R
      FAI1=PHIC
      FAI2=VZ3M(I,JS)/U3
      AAA1=SAREA(I)
      AAA2=SAREAS(I)
      ALFA1=BET2M(I,1)*RAD
      ALFA2=BET3M(I,JS)*RAD
      ALFA3=0.0
      IF(I.LT.NSTA) ALFA3=BET2M(I+1,1)*RAD
      BETA1=BAT2MR(I,JS)
      BETA2=BET3MR(I,JS)
      AINCIR=RINCM(I)
      AINCIS=SINCM(I)
      ADEVIR=RDEV(I)
C *** WRITE THE OUTPUT
      WRITE(6,404) FAIO,ISTAGE
  404 FORMAT(1H1,1X,≠*********************   ≠,1X,
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F5.3,1X,≠(STAGE=≠,I2,1X,
     $≠)≠,2X,≠********************≠)
       WRITE(6,401) PRATIO,TRATIO,ETAC
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)
       WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)
  402 FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,
     $6X,≠ROTOR SPEED=≠,F7.2,/)
      WRITE(6,405)
  405 FORMAT(1H0,24X,≠*ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*≠)
```

```
      TS= TT(I)*(RHOS/RHOT)**GM1
      RHOS1=RHOS
      TS1=TS
      PS1=PT(I)*(TT(I)/TS1)**(-GF2)
      WCAL=RHOS*VZ*AREA2(I)
      IF((ABS(WCAL-WTFLOW)/WCAL).GT.0.005)  GO TO 100
      PHIC = VZ/U2
      IF(PHIC.GT.PHI(I,JS,NPTS)) GO TO 120
      DO 200 I=1,NSTA
      DO 200 J=1,NSPE
      DO 200 K=1,NPTS
      PSI(I,J,K)=PSI1L(I,J,K)
      IF(XWW(1).GT.0.0.AND.XWW(1).LE.0.05) PSI(I,J,K)=PSI2L(I,J,K)
      IF(XWW(1).GT.0.05.AND.XWW(1).LE.0.10)PSI(I,J,K)=PSI3L(I,J,K)
      IF(XWW(1).GT.0.10.AND.XWW(1).LE.0.15)PSI(I,J,K)=PSI4L(I,J,K)
      IF(XWW(1).GT.0.15) PSI(I,J,K)=PSI5L(I,J,K)
  200 CONTINUE
      I=ISTAGE
      DO 130  K=2,NPTS
      IF(PHIC-PHI(I,JS,K))  140,150,130
  130 CONTINUE
      K= NPTS
  140 PSIC=(PSI(I,JS,K)-PSI(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
     1     (PHI(I,JS,K)-PHI(I,JS,K-1)) + PSI(I,JS,K-1)
      ETAC=(ETA(I,JS,K)-ETA(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
     1     (PHI(I,JS,K)-PHI(I,JS,K-1)) + ETA(I,JS,K-1)
      GO TO 160
  150 PSIC= PSI(I,JS,K)
      ETAC= ETA(I,JS,K)
  160 CONTINUE
      CALL CSETAL(I,J,K,XWW(1),PHIREF(I),PHIC,ETAC,ETAREF(I))
      PR(I) = (1.0 + PSIC*U3*U3/     (GJ*CP*TT(I)))**GF2
      TAU = PSIC/ETAC
      TR(I)= 1.0 + (PR(I)**GF3-1.0)/ETAC
      TT(I+1)= TT(I)*TR(I)
      PT(I+1)= PT(I) *PR(I)
      TRO(I)= TT(I+1)/TO
      PRO(I)= PT(I+1)/PO
      GF3S = GF3
      GF30= (GF3 + GF3S)/2.0
      ETAO(I)= (PRO(I)**GF30 - 1.0)/(TRO(I) - 1.0)
      VT2M = VZ * TAN(BET2M(I,1))
      VT2MR = UMM2   - VT2M
      BAT2MR(I,JS)= ATAN2(VT2MR,VZ)
      RINCM(I)= BAT2MR(I,JS) * RAD - RK2M(I)
      V2MR= VZ/COS(BAT2MR(I,JS))
      RHOT= PT(I+1)/(TT(I+1)*RG)
      TS= TT(I+1)
      RHOS= RHOT
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)
  161 VZ3M(I,JS)=WTFLOW/(RHOS*AREA3(I))
      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UMM2  *VT2M)/UMM3
      VS= VZ3M(I,JS)**2 + VT3M**2
      CP=CPFM(TS)
      RHOS= RHOT*(1.0-VS/(G2J*CP*TT(I+1)))**GF1
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)
      IF((VS).GT.(G2J*CP*TT(I+1))) GO TO 113
      TS= TT(I+1) * (RHOS/RHOT)**GM1
      RHOS2=RHOS
      TS2=TS
      PS2=PT(I+1)*(TT(I+1)/TS2)**(-GF2)
      WCAL=RHOS*AREA3(I)*VZ3M(I,JS)
      IF(ABS(WCAL-WTFLOW).GT.0.005)  GO TO 161
      BET3M(I,JS) = ATAN2(VT3M,VZ3M(I,JS))
      SINCM(I) = BET3M(I,JS)*RAD - SK2M(I)
      VT3MR = UMM3   - VT3M
      BET3MR(I,JS)= ATAN2(VT3MR,VZ3M(I,JS))
      V3MR = VZ3M(I,JS)/COS(BET3MR(I,JS))
      RDFM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +
     XRM2(I))/RSOLM(I)/V2MR
```

```
     X, OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                                COUPT
     X, RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                         COUPT
     X, SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                         COUPT
     X, SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)        COUPT
     X, SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)        COUPT
     X, UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI       COUPT
     X, AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT       COUPT
     X, ICENT,IICENT,FMR1(6),FMA2(6),IRAD,FAID                           COUPT
     X, NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                       COUPT
     X, DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)             COUPT
     X, DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                   COUPT
     X, BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)        COUPT
      COMMON /VECTOR/ CPCO(6), TITLE(12), RT2(12), RH2(12), RT3(12),     COUPT
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),       COUPT
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9 COUPT
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),        COUPT
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12), COUPT
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12) COUPT
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12)  COUPT
     X,BAT2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(   COUPT
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12 COUPT
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)        COUPT
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR COUPT
     X(12,9),B2MB3R(12,9),SPEEDF,FLOWIN,V3DV2R(12),V2V3(12),DB3MRG(12)   COUPT
     X,DB3MRN(12,9), DB3MRP(12,8),CPCM(6),CPCS(6)                        COUPT
     *,RK3M(12),RDEV(12),RDEF(12),GMREF(12)                              COUPT
     *,PSID1(12,2,8),PSID2(12,2,8),PSID3(12,2,8),PSID4(12,2,8)           COUPT
     *,PSID5(12,2,8),PSI1(12,2,8),PSI2(12,2,8),PSI3(12,2,8)              COUPT
     *,PSI4(12,2,8),PSI5(12,2,8)                                         COUPT
     *,PSID1L(12,2,8),PSID2L(12,2,8),PSID3L(12,2,8)                      COUPT
     *,PSID4L(12,2,8),PSID5L(12,2,8),PSI1L(12,2,8)                       COUPT
     *,PSI2L(12,2,8),PSI3L(12,2,8),PSI4L(12,2,8),PSI5L(12,2,8)           COUPT
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA COUPT
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                        COUPT
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP     COUPT
     X,XAR,XMET,XSTM                                                     COUPT
     X,STAGEN,SPEEDN,CHAPTS,WTMOLE                                       COUPT
      FLOWIN=FLOW1                                                       COUPT
      DFLOW=FLOWIN                                                       COUPT
      FLOWFI=FLOWIN                                                      COUPT
      IF (UNITS.NE.1.0) GO TO 81                                         COUPT
      FLOWIN = FLOWIN/0.453592                                           COUPT
      DFLOW  =  DFLOW/0.453592                                           COUPT
      FLOWFI = FLOWFI/0.453592                                           COUPT
   81 CONTINUE                                                           COUPT
      JS=1                                                               COUPT
      DO 82 J=1,NSPE                                                     COUPT
      IF (SPEEDF.EQ.PCTSPD(J)) JS=J                                      COUPT
   82 CONTINUE                                                           COUPT
C *** CALCULATE THE OUTPUT                                               COUPT
      I=ISTAGE                                                           COUPT
      TT(I)=TG(1)                                                        COUPT
      PT(I)=P(1)                                                         COUPT
      WTFLOW = FLOWIN                                                    COUPT
      RHOT= PT(I)/(TT(I)*RG)                                             COUPT
      TS= TT(I)                                                          COUPT
      RHOS= RHOT                                                         COUPT
      RHOW=62.3                                                          COUPT
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)                          COUPT
      WTFLOW = WTFLOW - FLOWIN*BLEED(I,JS)                               COUPT
      U2 = UT2(I)*SPEEDF                                                 COUPT
      U3 = UT3(I)*SPEEDF                                                 COUPT
      UMM2 = UM2(I)*SPEEDF                                               COUPT
      UMM3 = UM3(I)*SPEEDF                                               COUPT
  100 VZ=WTFLOW/(RHOS*AREA2(I))                                          COUPT
      V= VZ/COS(BET2M(I,1))                                              COUPT
      CP=CPFM(TS)                                                        COUPT
      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))**GF1                           COUPT
      RHOSM=1.0/((1.0-XWT(1))/RHOS+XWT(1)/RHOW)                          COUPT
      IF ((V*V).GT.(G2J*CP*TT(I))) GO TO 113                             COUPT
```

```
      WRITE(6,406) P(1),P(2),P(3)                                       COUPT
  406 FORMAT(1H ,1X,≠TOTAL PRESSURE≠,10X,3(F10.4,5X))                    COUPT
      WRITE(6,407) PS1,PS2                                              COUPT
  407 FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,2(F10.4,5X))                    COUPT
      WRITE(6,408) TG(1),TG(2),TG(3)                                    COUPT
  408 FORMAT(1H ,1X,≠TOTAL TEMPERATURE(GAS)≠,3X,3(F10.4,5X))             COUPT
      WRITE(6,409) TS1,TS2                                              COUPT
  409 FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,2(F10.4,5X))            COUPT
      WRITE(6,410) RHOG(1),RHOG(2)                                      COUPT
  410 FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,2(F10.4,5X))                COUPT
      WRITE(6,412) VZ1,VZ2                                              COUPT
  412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,2(F10.4,5X))                    COUPT
      WRITE(6,413) V1,V2                                                COUPT
  413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,2(F10.4,5X))                  COUPT
      WRITE(6,414) W1,W2                                                COUPT
  414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))                  COUPT
      WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)                    COUPT
  415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))                       COUPT
      WRITE(6,416) VS1,VS2                                              COUPT
  416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))              COUPT
      WRITE(6,417) WS1,WS2                                              COUPT
  417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))              COUPT
      WRITE(6,418) ASPED1,ASPED2                                        COUPT
  418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,2(F10.4,5X))                    COUPT
      WRITE(6,419) AMAC1,AMAC2                                          COUPT
  419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,2(F10.4,5X))               COUPT
      WRITE(6,420) AMACH1,AMACH2                                        COUPT
  420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))               COUPT
      WRITE(6,421) FAI1,FAI2                                            COUPT
  421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,2(F10.4,5X))                   COUPT
      WRITE(6,422) AAA1,AAA2                                            COUPT
  422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,2(F10.4,5X))                         COUPT
      WRITE(6,423) ALFA1,ALFA2,ALFA3                                    COUPT
  423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))                COUPT
      WRITE(6,424) BETA1,BETA2                                          COUPT
  424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))                COUPT
      WRITE(6,425) AINCIR,AINCIS                                        COUPT
  425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))                         COUPT
      WRITE(6,426) ADEVIR                                               COUPT
  426 FORMAT(1H ,1X,≠DEVIATION≠,30X,1(F10.4,5X))                         COUPT
      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW/0.453592                        COUPT
      GO TO 111                                                         COUPT
  110 WRITE(6,2100) I,PHIC                                              COUPT
 2100 FORMAT (10H FOR STAGE,13,18H , COMPUTED PHI IS,F8.4,06H STALL)    COUPT
      GO TO 111                                                         COUPT
  120 WRITE(6,2110)I,PHIC                                               COUPT
 2110 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H CHOKE)    COUPT
      GO TO 113                                                         COUPT
  111 FLOWIN=FLOWIN+DFLOW                                               COUPT
      IF (FLOWIN.LE.FLOWFI) GO TO 81                                    COUPT
  113 CONTINUE                                                          COUPT
      DO 112 I=1,NSTA                                                   COUPT
      DO 112 J=1,NSPE                                                   COUPT
  112 DPSIS(I,J) = 0.0                                                  COUPT
      RETURN                                                            COUPT
      END                                                               COUPT
```

| | | |
|---|---|---|
| 1. Report No. NASA CR-3624 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle WISGSK - A COMPUTER CODE FOR THE PREDICTION OF A MULTISTAGE AXIAL COMPRESSOR PERFORMANCE WITH WATER INGESTION | | 5. Report Date NOVEMBER 1982 |
| | | 6. Performing Organization Code |
| 7. Author(s) T. Tsuchiya and S. N. B. Murthy | | 8. Performing Organization Report No. None |
| 9. Performing Organization Name and Address Purdue University School of Mechanical Engineering West Lafayette, Indiana 47907 | | 10. Work Unit No. |
| | | 11. Contract or Grant No. NAG-3-62 |
| 12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546 | | 13. Type of Report and Period Covered Contractor Report |
| | | 14. Sponsoring Agency Code 505-32-2A (E-1242) |

15. Supplementary Notes

Final report. Project Manager, Ronald J. Steinke, Fluid Mechanics and Acoustics Division, NASA Lewis Research Center, Cleveland, Ohio 44135.

16. Abstract

A computer code is presented for the prediction of off-design axial flow compressor performance with water ingestion. Four processes have been considered to account for the aero-thermo-mechanical interactions during operation with air-water droplet mixture flow: (i) blade performance change, (ii) centrifuging of water droplets, (iii) heat and mass transfer process between the gaseous and the liquid phases and (iv) droplet size redistribution due to break-up. Stage and compressor performance are obtained by a stage stacking procedure using representative velocity diagrams at a rotor inlet and outlet mean radii. The Code has options for performance estimation with (a) mixtures of gas and (b) gas-water droplet mixtures, and therefore can take into account the humidity present in ambient conditions. A test case illustrates the method of using the Code. The Code follows closely the methodology and architecture of the NASA-STGSTK Code for the estimation of axial-flow compressor performance with air flow.

| 17. Key Words (Suggested by Author(s)) | | 18. Distribution Statement |
|---|---|---|
| Compressor off-design | Water ingestion | Unclasssified - unlimited |
| Axial-flow compressor | Water droplets | STAR Category 07 |
| Multistage compressor | Stage stacking | |
| Two phase flow | | |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | 256 | A12 |

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1982